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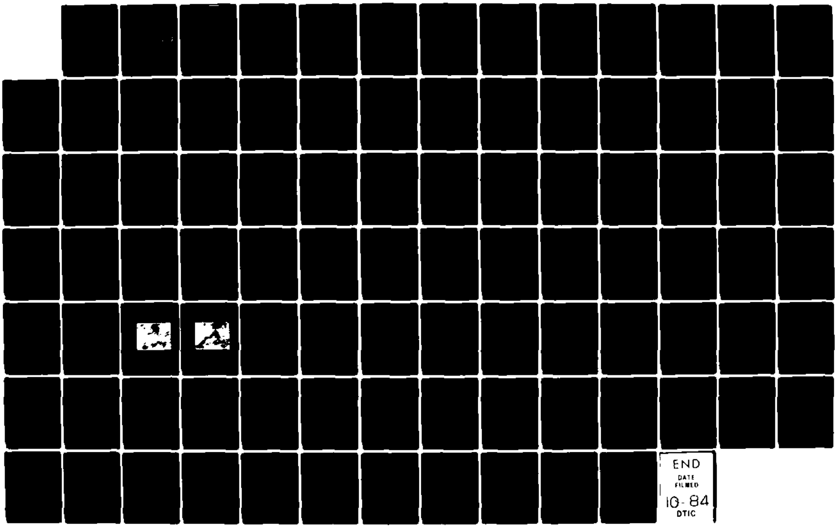

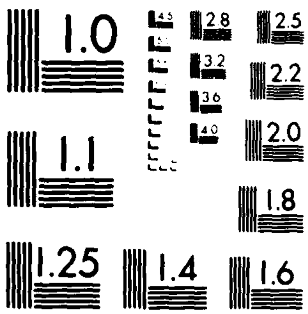


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# DIGEST

Soundings of atmospheric thermodynamic structure from GOES-VAS satellite retrievals are used to investigate a severe storm outbreak over the central United States on 21-22 July 1982. The satellite soundings are available at six times between 1100 and 2300 GMT 21 July. They are objectively analyzed to achieve meso $\alpha$-scale resolution. The goal is to assess the usefulness of VAS data in diagnosing the changes in atmospheric structure that are conducive to storm formation.

Just prior to thunderstorm development, increasing instability due to low-level warming, middle tropospheric cooling, and increasing water vapor content are detected. Several triggering mechanisms in the area explain the pattern of convection that follows. Though the VAS soundings appear to overestimate the atmospheric instability when compared to rawinsonde soundings, the general continuity of features in space and time is good. A second limitation of the VAS data is that extensive cloud cover limits the number of retrievals early in the study period.

The research demonstrates that VAS soundings are a useful supplement to the standard 12 h rawinsonde data during this case. However, the retrieval algorithms should be investigated to determine whether any of the observed variations are attributable to deficiencies in these procedures.

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USING VAS-DERIVED THERMODYNAMIC PARAMETERS

Michael Francis Remeika, B.A., B.S.

A Digest Presented to the Faculty of the Graduate School
of Saint Louis University in Partial Fulfillment of
the Requirements for the Degree of
Master of Science (Research)

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A Thesis Presented to the Faculty of the Graduate School
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Master of Science (Research)

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TABLE OF CONTENTS


| Title | Page |
|---|---|
| Acknowledgements .................................... | iii |
| Table of Contents .................................... | iv |
| List of Tables .................................... | vi |
| List of Figures .................................... | vii |
| 1. INTRODUCTION .................................... | 1 |
| a. <u>Motivation for investigation</u> .................... | 1 |
| b. <u>Past studies</u> .................................... | 2 |
| 1) General concepts ............................ | 2 |
| 2) Quantitative evaluations of polar-orbiter data .................................... | 5 |
| 3) Polar-orbiter investigations of meteorological phenomena .............................. | 7 |
| 4) The VAS instrument ........................... | 9 |
| 5) Quantitative studies using VAS ................ | 13 |
| 6) VAS investigations of mesoscale features ....... | 14 |
| c. <u>Objectives</u> .................................... | 15 |
| 2. METHODOLOGY .................................... | 17 |
| a. <u>Case selection</u> .................................... | 17 |
| b. <u>Sounding retrievals</u> ............................ | 20 |
| c. <u>Editing at Saint Louis University</u> ................ | 22 |

TABLE OF CONTENTS (CONTINUED)


| Title | Page |
|---|---|
| d. *Objective analysis* | 23 |
| 3. WEATHER CONDITONS | 35 |
| 4. RESULTS | 47 |
| a. *Geopotential height* | 47 |
| b. *Temperature* | 51 |
| c. *Precipitable water* | 53 |
| d. *Stability* | 58 |
| 5. SUMMARY AND CONCLUSIONS | 72 |
| REFERENCES | 75 |
| BIOGRAPHY OF THE AUTHOR | 79 |

## LIST OF TABLES


| Table | | Page |
|---|---|---|
| 1 | VAS instrument characteristics (after Smith *et al.*, 1981b) | 10 |
| 2 | Image areas and times for sounding retrievals on 21 July 1982 | 18 |
| 3 | Spin budgets for Dwell Image and Dwell Sounding retrievals | 19 |
| 4 | Number of soundings after editing within the computational domain | 27 |

## LIST OF FIGURES

| Figure | | Page |
|---|---|---|
| 1 | VAS weighting functions for the seven temperature (top) and three moisture (bottom) sounding channels (after Chesters et al., 1982) ............ | 11 |
| 2 | VAS sounding locations for 21 July 1982 ........... | 24 |
| 3 | Response curves used to objectively analyze the VAS and rawinsonde soundings ...................... | 30 |
| 4 | VAS subjective (SUB) and objective (OBJ) analyses at 850 and 200 mb for 1600 and 1700 GMT 21 July ............................................ | 31 |
| 5 | Surface and 500 mb National Meteorological Center (NMC) analyses for 1200 GMT 21 July and 0000 GMT 22 July .................................. | 36 |
| 6 | Surface temperatures for 1200 GMT 21 July, 1800 GMT 21 July, and 0000 GMT 22 July ................. | 38 |
| 7 | NMC radar summaries with echo tops in km .......... | 41 |
| 8 | GOES visible image at 1700 GMT 21 July (a) and GOES IR image at 2000 GMT 21 July (b) ............ | 43 |
| 9 | VAS-derived 500 mb analyses at 1700, 2000, and 2300 GMT .......................................... | 48 |
| 10 | VAS-derived thicknesses for the 850-500 and 500-300 mb layers at 1700 GMT 21 July ............. | 52 |
| 11 | Precipitable water (mm) for the surface to 300 mb layer from rawinsonde data at 1200 GMT 21 July and 0000 GMT 22 July and from VAS data at 1700, 2000, and 2300 GMT 21 July ................. | 54 |
| 12 | Changes in precipitable water (mm) for the surface to 300 mb layer between 1600 to 1700 GMT and 1700 to 2000 GMT 21 July ..................... | 57 |

LIST OF FIGURES (CONTINUED)


| Figure | | Page |
|---|---|---|
| 13 | VAS-derived precipitable water (mm) for the 500-300 mb layer at 1700 GMT 21 July .............. | 59 |
| 14 | Lifted Indices from rawinsonde data at 1200 GMT 21 July and 0000 GMT 22 July and from VAS data at 1700, 2000, and 2300 GMT 21 July ............... | 61 |
| 15 | Changes in the Lifted Index between 1600 to 1700 GMT and 1700 to 2000 GMT 21 July .................. | 64 |
| 16 | Skew T-log P profiles from VAS data at 1600, 1700, and 2300 GMT 21 July and from rawinsonde data at 0000 GMT 22 July at Points A, B, and C (see Figs. 11, 14) ................................ | 66 |

# 1. INTRODUCTION

## a. Motivation for investigation

Many important meteorological phenomena occur at the mesoscale. These systems have wavelengths of 2-2000 km and lifetimes of several hours (Orlanski, 1975). Unfortunately, however, short-range prediction of mesoscale events has not advanced as rapidly as has prediction of the synoptic and planetary scales of motion. There are several explanations for the forecasting limitations in mesometeorology. First, there are mathematical and theoretical difficulties in developing prediction models for these smaller scales. Second, although large amounts of data are required to describe the features, the time available for data processing and interpretation, and for the dissemination of results, is short. Finally, data from the routine rawinsonde network are too coarse in resolution to properly define mesoscale weather events since observations are taken every 12 h at an average station spacing of only 400 km.

Satellite-derived soundings from the Nimbus and TIROS-N/NOAA series, for example, have provided a global or near-global data source, thereby reducing some of the gaps that occur over the oceans and over the less developed land regions. However, each satellite only passes over a given location twice daily. This is insufficient for resolving the temporal evolution of most

mesoscale events.

A major advance in meteorological satellite technology is the geostationary platform (GOES series) from which imagery is available at intervals shorter than 1 h. The most recent GOES satellites contain the Visible Infrared Spin-Scan Radiometer (VISSR) Atmospheric Sounder (VAS) which provides radiance data from which retrievals of atmospheric temperature and water vapor structure can be obtained on the mesoscale. Because of its greatly improved data collection frequency in comparison to the polar-orbiters, the GOES-VAS system shows much promise for improved diagnosis and forecasting of subsynoptic-scale phenomena such as severe thunderstorms.

This investigation will describe the use of VAS soundings in the diagnosis of a convective environment that produced intense thunderstorm activity.

## b. Past studies

### 1) General concepts

It is useful to discuss several important concepts about satellite-derived soundings. First, they are fundamentally different in nature from rawinsonde data. The rawinsonde is virtually a point source sensor, but the satellite's radiometer detects radiances arising from atmospheric volumes having a depth of several kilometers and a horizontal area of several hundred square kilometers. The volume-averaged data are then transformed

into temperature and humidity values for a single location as a function of discrete pressure levels (e.g., Lee _et al._, 1983; Smith, 1983). This volumetric sampling results in a smoother than desired definition of atmospheric structure. As a result, vertically integrated parameters such as precipitable water and geopotential thickness generally are favored over those such as temperature or dewpoint temperature.

An important problem associated with satellite-derived retrievals is the extraction of "clear-column radiances" which contribute to decreased accuracy within areas of cloud cover (Smith _et al._, 1979b). An interesting aspect of this point is that partly cloudy retrievals have been shown to be more accurate than either clear or cloudy retrievals in the lower and middle troposphere (e.g., Phillips _et al._, 1979). This leads to the speculation that clear retrievals are contaminated more easily than partly cloudy retrievals. Since cloud droplets are radiatively inactive at some frequencies in the microwave spectral region, soundings can be made based on observed radiances in the microwave spectral region when clouds are present. The Microwave Sounding Unit (MSU), contained on board TIROS-N (Smith _et al._, 1979b, 1981a), is similar to the Scanning Microwave Spectrometer (SCAMS) which has been flown on the Nimbus-6 series of satellites (Moyer _et al._, 1978) for this purpose. Unfortunately, however, microwave sensors are not part of the current VAS system.

A major limitation of all satellite sounding schemes is their inability to adequately resolve temperature inversions (e.g., Chesters et al., 1982; Togstad and Horn, 1974). Although satellite-derived profiles do not capture the complete vertical structure exhibited by rawinsonde data, this lack of detail is compensated by improved horizontal resolution. Regarding TIROS-N, Smith et al. (1981a) stated that soundings produced globally using the TIROS-N Operational Vertical Sounder (TOVS) have a horizontal spacing of 250 km. A higher resolution of 50 km is achieved for limited geographical regions using man-machine interactive processing methods (Smith et al., 1979a).

Although it is customary to judge satellite retrievals by comparison with rawinsonde data (e.g., Tracton and McPherson, 1977; Wilcox and Sanders, 1976), exact methods for this purpose vary, and they are not entirely satisfactory. A major limitation of the evaluation procedure is that rawinsonde and satellite soundings usually are not precisely co-located in space and/or time. Thus, this type of discrepancy between the two data types should be removed, if possible, in order to isolate true differences between the measurement systems. In attempting to overcome the problem, linearly time-weighted means of bracketing rawinsonde observations are often used as ground truth for satellite data (Anderson et al., 1982; Jedlovec, 1984; Moyer et al., 1978; Petersen and Horn, 1977; Petersen et al., 1982; Smith and Zhou, 1982; Smith et al., 1979b, 1981a, b, c). The assumption of

linear atmospheric variations over periods of 12 h rawinsonde observations is questionable, but usually unavoidable. In a recent study of mesoscale satellite soundings, Jedlovec (1984) adjusted the 3 h ground truth rawinsonde data to a common time thereby removing effects due to variations in times of release and sonde ascent rates. Concerning differences in sounding locations, satellite retrievals can either be paired with the nearest rawinsonde sounding (e.g., Moyer _et al_., 1978) or comparisons can be made from grid point objective analyses of each source (e.g., Jedlovec, 1984; Koch _et al_., 1983). Although the "comparisons approach" of verifying satellite retrievals assumes that the rawinsonde data are error free, this is obviously not the case (Hoehne, 1980; Lenhard, 1970). To summarize this point, McMillan _et al_. (1983) recently noted that satellite accuracies are approaching the accuracies of the estimates of the ground truth data when the combined effects of rawinsonde errors and differences in time and location are considered.

2) Quantitative evaluations of polar-orbiter data

Using the above mentioned techniques, numerous studies have quantitatively compared rawinsonde- and satellite-derived soundings. Moyer _et al_. (1978) found the standard deviation of temperature discrepancies from routine Nimbus-6 data tó be approximately 1.5 $^{o}$C from 850-300 mb, decreasing to about 1 $^{o}$C from 250-100 mb. In a study of Nimbus-6 and TIROS-N data, Schlatter (1981) observed that root-mean-square (RMS) differences between

layer temperatures were generally less than 2 $^{o}$C, except in the 1000-850 and 70-50 mb layers, where values were larger. He also noted the consensus that RMS retrieval errors for these two satellite systems ranged between 1.5 and 2.5 $^{o}$C. These values are in close agreement with those for Nimbus-5 (Arnold et al., 1976; Waters et al., 1975; Wilcox and Sanders, 1976). Other quantitative evaluations of TIROS-N soundings include those by Phillips et al. (1979) and Smith et al. (1979b, 1981a).

A somewhat different, and perhaps more satisfactory, evaluation procedure is the use of structure function analyses to quantify random errors contained in the soundings. This technique does not include systematic differences, and it does not require the satellite retrievals to be compared with rawinsonde data. Using this technique on NOAA-4 soundings, Hillger and Vonder Haar (1979) estimated the RMS noise level to be approximately 0.5 $^{o}$C. This value is considerably smaller than that obtained from the conventional procedures.

An alternate approach to satellite sounding verification is to create synthetic soundings from rawinsonde data and then compare the results with the original soundings. This procedure was used by Togstad and Horn (1974) to evaluate satellite representations of frontal inversions and the tropopause. Similarly, Chesters et al. (1982) assessed the ability of satellite retrievals to portray convectively unstable environments.

3) Polar-orbiter investigations of meteorological phenomena

Numerous studies have qualitatively analyzed the time continuity of satellite-derived fields of parameters such as temperature, precipitable water, and thickness. Comparisons were made with patterns from rawinsonde data. Results have generally shown that satellite-derived synoptic-scale features show good continuity and agreement with those from the traditional source. Of course, a desired outcome is that the satellite retrievals detect features which may be missed in the objective analysis of the routine upper air data. In that regard, Togstad and Horn (1974) investigated the sensor's ability to resolve thermal support for a propagating upper-level jet streak. The retrieval algorithm was successful in describing the general thermal structure of the atmosphere, and it was possible to retrieve the geostrophic wind field with approximately the same detail as provided by the current rawinsonde network. A weakness of the retrievals was their inability to resolve temperature inversions. This resulted in a smoothing of the strong vertical wind shears characteristic of the jet streak.

In another investigation, carefully screened Nimbus-6 soundings at a horizontal resolution of 250 km were capable of delineating the location and intensity of mass and momentum fields associated with a closed 500 mb low over land (Petersen and Horn, 1977). The gradual progression of the low agreed with that observed from rawinsonde reports. Although the satellite's

geostrophically-derived isotach fields were biased too low, the 500 mb velocity maxima showed reasonable continuity. These agreements between satellite and rawinsonde data over land suggested that equally good results could be expected over oceanic areas, given adequate sea level pressure observations.

With an improving sounding product at the synoptic scale, recent efforts have focussed on extracting mesoscale retrievals from the polar-orbiting satellites. Smith et al. (1979b, 1981a) described characteristics of TIROS-N sounding data prepared at operational (250 km) and special mesoscale (50 km) resolutions. The operational soundings exhibited sufficient information content for independent synoptic-scale analyses. However, by using man-machine interactive processing techniques, subsynoptic-scale features below the resolution of the operational product could be isolated. These smaller scale disturbances appeared to be related to severe weather events.

Using high resolution radiance data from the NOAA and Nimbus series, Hillger and Vonder Haar (1977, 1981) obtained mesoscale temperature and moisture soundings at intervals between 30-70 km. Although temperatures often were biased 1-2 $^{o}$C due to cloud contamination, measures of precipitable water were relatively unaffected. During a pre-convective case, the satellite data located perturbations on a dry line, although only its general position had been detected by the regular surface observations. Areas of convective activity that developed between 2-2.5 h after the

satellite pass correlated well with local maxima of moisture and instability seen in the satellite-derived analyses.

The above mentioned studies indicate that mesoscale spatial details can be obtained from polar-orbiting platforms; however, soundings at mesoscale time intervals must be obtained from geostationary systems such as GOES-VAS.

4) The VAS instrument

GOES-4, launched in November 1980, contained a new instrument, called the VISSR Atmospheric Sounder (VAS). This radiometer has imaging capabilities in a visible channel and twelve Infrared (IR) channels between 3.9 and 15 μm (Table 1), thereby allowing sounding estimates to be made from geostationary orbit for the first time.

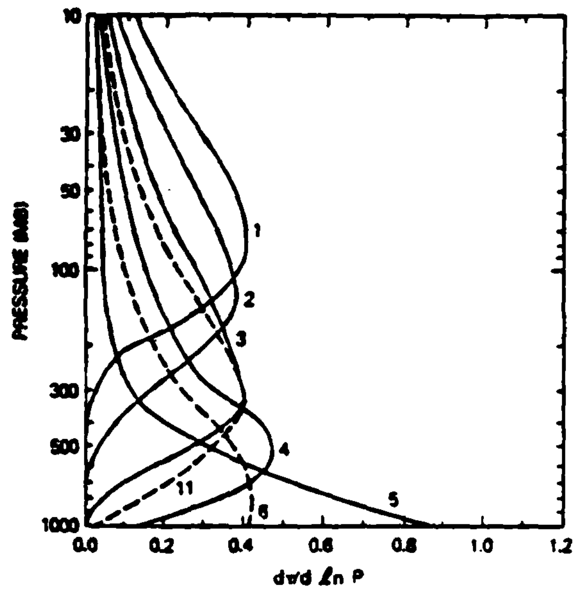
The GOES satellite, which contains the VAS, spins in a west to east direction at 100 rpm. Depending on the IR channel, the nadir resolution is either 7 or 14 km. Each curve in Fig. 1 shows the sensitivity of the radiance observed in the spectral interval of the indicated channel to a local variation in atmospheric temperature. These are usually referred to as weighting functions ($\tau$) because they appear in this fashion in the integral equations relating temperature to the observed radiances. These weighting functions vary somewhat according to the water vapor and ozone content of the atmosphere, and also weakly with temperature. In the figure, P represents pressure. As usual, peaks in the func-

Table 1. VAS instrument characteristics (after Smith et al., 1981b).

| Spectral channel | Central wavelength (μm) | Central wavenumber ($cm^{-1}$) | Weighting function peak (mb) | Absorbing constituent | Inflight single sample noise ($mW\ m^{-2}\ sr^{-1}\ cm^{-1}$) | Typical spin budget[1] | Typical sounding radiance noise[2] ($mW\ m^{-2}\ sr^{-1}\ cm^{-1}$) |
|---|---|---|---|---|---|---|---|
| 1 | 14.71 | 679.95 | 40 | $CO_2$ | 4.125 | 2 | 0.583 |
| 2 | 14.45 | 691.90 | 70 | $CO_2$ | 2.525 | 4 | 0.253 |
| 3 | 14.23 | 702.39 | 150 | $CO_2$ | 1.763 | 7 | 0.133 |
| 4 | 13.99 | 714.35 | 450 | $CO_2$ | 1.438 | 7 | 0.112 |
| 5 | 13.31 | 751.37 | 950 | $CO_2$ | 1.131 | 4 | 0.113 |
| 6 | 4.52 | 2214.35 | 950 | $CO_2$ | 0.028 | 7 | 0.002 |
| 7 | 12.66 | 789.39 | surface | $H_2O$ | 1.069 | 3 | 0.123 |
| 8 | 11.24 | 889.52 | surface | window | 0.119 | 1 | 0.024 |
| 9 | 7.25 | 1379.69 | 600 | $H_2O$ | 1.225 | 9 | 0.082 |
| 10 | 6.73 | 1486.33 | 400 | $H_2O$ | 0.306 | 2 | 0.043 |
| 11 | 4.44 | 2254.28 | 500 | $CO_2$ | 0.026 | 7 | 0.002 |
| 12 | 3.94 | 2538.07 | surface | window | 0.007 | 1 | 0.001 |

[1]Number of spins sensed by the same detector with filter and mirror positions fixed.

[2]After averaging 25 samples in one sounding area.



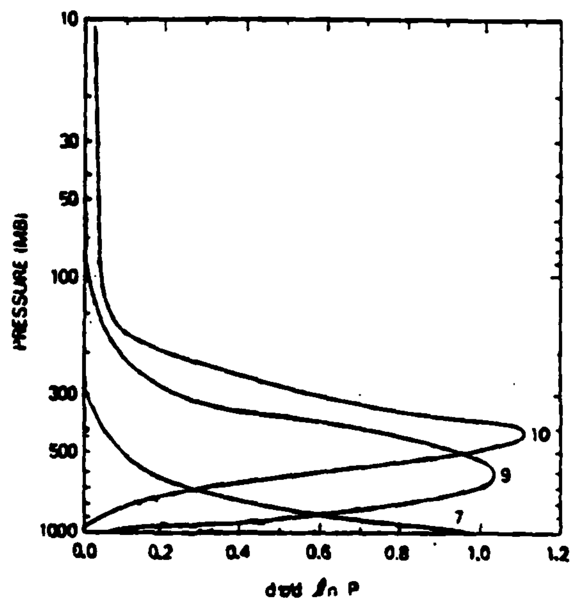




Fig. 1. VAS weighting functions for the seven temperature (top) and three moisture (bottom) sounding channels (after Chesters et al., 1982).

tions are quite broad. The relative sharpness in the moisture channels is due to the rapid decrease in water vapor with height. Chesters et al. (1982) noted that the lower troposphere is not well resolved by any VAS channel.

The VAS can operate in three separate modes. The VISSR mode provides the usual visible and 11 μm images, although it is possible to substitute one of the new IR channels for the 11 μm data (Anderson et al., 1982). The Multi-Spectral Imaging (MSI) mode provides data from the visible and any three IR channels. Finally, the Dwell Sounding (DS) mode can produce images from all twelve channels so that vertical soundings of temperature and humidity can be retrieved. Noise within the radiances is reduced by averaging several spins on the same scan line and channel. The number of spins per channel for this purpose is called the spin budget. After data collection, spatial averaging of several radiance values at 14 km resolution can be performed to further reduce noise. More complete descriptions of the VAS instrument and its operating modes are given by Chesters et al. (1982), Menzel et al. (1981), and Smith et al. (1981c).

The potential for GOES-VAS to aid in mesoscale applications is evident when one considers that sounding quality radiances are possible every hour for an east-west swath covering the north-south extent of the coterminous United States. Sounding retrievals can be made at separations of 75-100 km. At present, GOES-VAS is still in the evaluation stage and is non-operational.

5) Quantitative studies using VAS

Several investigations have sought to verify the mesoscale capabilities of the VAS instrument. The few results published thus far are very promising. Temperature residuals in the VAS simulation experiment conducted by Chesters et al. (1982) were found to be only ±1 °C. However, they expected operational temperature errors to be about ±2 °C because the simulated radiances had been calculated for optimal clear-sky conditions. Simulations of retrieved fields of precipitable water produced uncertainties of ±2 mm, whereas errors in the 500-920 mb thickness were only ±3.3 m. The conclusion was that VAS should be able to detect convectively unstable conditions suitable for thunderstorm activity.

A recent study by Jedlovec (1984) evaluated VAS soundings prepared using physical (Smith, 1983) and regression (Lee et al., 1983) retrieval algorithms. Only one day was considered, and the region of interest contained a strong frontal inversion in the lower to middle troposphere. Both schemes produced a warm bias in the lowest layer up to 850 mb, a cold bias up to 600 mb, and another warm bias existing throughout a 300 mb layer above. Maximum differences of 2-3 °C occurred between 400 and 500 mb. These results differ from those of most previous studies involving other satellite systems (e.g., Phillips et al., 1979; Smith et al., 1979b; Waters et al., 1975) and which were based on much longer periods of comparison. Those investigators found that smallest biases were located in the middle troposphere whereas

largest differences occurred near the surface and the tropopause level. Thus, Jedlovec's findings for a single case are probably not representative of longer time scales. Concerning the humidity data, Jedlovec (1984) found that the VAS physical retrievals overestimated the low-level moisture and underestimated it aloft. Vertical profiles and statistical data for the regression-derived humidity parameters were promising, but they did not adequately describe the horizontal moisture structure detected by a special mesoscale rawinsonde network. Gradients of temperature and height from both satellite-derived data sets were good representations of those from the rawinsondes; however, magnitudes were reduced between 30-50%.

6) VAS investigations of mesoscale features

The potential impact of VAS soundings on nowcasting capabilities were dramatically demonstrated by Smith et al. (1981b) using newly available 6.7 μm water vapor images and DS physical retrievals. With real-time mesoscale identification of diurnal warming, moist tongue propagation, and dynamic instability, early delineation of atmospheric instability prior to intense convection was provided. Chesters et al. (1982) concluded that VAS retrievals should be able to isolate significant moisture gradients in convectively unstable regimes. They also evaluated the effects of various "first guess" sounding profiles on the final retrievals. Results demonstrated that mesoscale VAS soundings improve with conditioning by local weather statistics. VAS has

also been found useful in determining low-level water vapor content (Chesters _et al._, 1982). Using the "split window" technique involving the 11 and 12 μm channels, it was possible to monitor mesoscale developments in the low-level moisture fields over relatively cloud free areas. Anthony and Wade (1983) described uses of VAS retrievals by forecasters at the National Severe Storm Forecast Center. A major limitation was VAS's inability to sound through mid- or upper-level clouds. They also qualitatively evaluated VAS-derived parameters with rawinsonde-derived counterparts.

The previous research suggests that satellites provide a valuable source of meteorological data. VAS retrievals and images appear to be an especially promising source of vitally needed mesoscale information. Although there are many exciting new developments, much remains to be learned about the characteristics and uses of VAS data.

## _c_. _Objectives_

This report describes a detailed case study of the severe storm outbreak occurring between 1200 GMT 21 July and 0000 GMT 22 July 1982. VAS sounding data at mesoscale resolution are used to study the atmospheric structure during this period. The goals of the investigation are to:

1) determine those changes in atmospheric structure after the 1200 GMT 21 July rawinsonde releases that were conducive to thunderstorm formation later in the afternoon,

2) assess the relative strengths and weaknesses of VAS retrievals as a diagnostic tool, and

3) investigate techniques that utilize VAS data in the analysis and forecasting of convective outbreaks.

In pursuing these objectives, a major goal is to search for mesoscale features which could not be detected by the standard rawinsonde network or followed at 12 h intervals by polar-orbiting satellites.

## 2. METHODOLOGY

### a. Case selection

The period 21-22 July 1982 was chosen for study because it contained significant afternoon convection during a period when VAS data were available. It is a typical case in that the entire data region was not clear prior to thunderstorm development. VAS soundings were available at six times -- 1100, 1300, 1600, 1700, 2000, and 2300 GMT 21 July. Table 2 shows that each of the six data sets was prepared from two separate sectors -- a northern and a southern portion. Due to the small time difference between the two sections, they were treated as a single image for retrieval purposes.

The 1300 and 1600 GMT image pairs were collected during the satellite's "Dwell Image" mode, while those for the remaining four times were obtained during the DS mode. Table 3 gives spin budgets for each type. The important point is that the "Dwell Image" data were obtained with a reduced spin budget. Thus, the accuracy of their derived retrievals generally is expected to be somewhat less than those from the complete budget. This occurs because multiple scans are designed to improve the signal-to-noise ratios of the radiance data (Smith *et al.*, 1981a).

Table 2. Image areas and times for sounding retrievals on 21 July 1982.

| Sounding Time (GMT) | Image Time (GMT) | Latitude Coverage (deg) |
|---|---|---|
| 1100 | 1048 | 26-36 |
| | 1118 | 36-49 |
| 1300 | 1248 | 14-27 |
| | 1318 | 27-44 |
| 1600 | 1548 | 14-27 |
| | 1618 | 27-44 |
| 1700 | 1648 | 26-36 |
| | 1718 | 36-49 |
| 2000 | 1948 | 26-36 |
| | 2013 | 36-49 |
| 2300 | 2248 | 26-36 |
| | 2318 | 36-49 |

Table 3. Spin budgets for Dwell Image and Dwell Sounding retrievals.

| Type | Channel | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Dwell Image | 1 | 2 | 2 | 2 | 1 | 3 | 1 | 1 | 2 | 1 | 0 | 1 |
| Dwell Sounding | 1 | 3 | 4 | 3 | 2 | 6 | 2 | 1 | 3 | 1 | 0 | 1 |

## b. Sounding retrievals

VAS soundings were made at NASA/Marshall Space Flight Center (MSFC) using the Man-computer Interactive Data Access System (McIDAS) processing techniques that are outlined in Smith et al. (1979a). The physical retrieval algorithm of Smith (1983) was employed by personnel having considerable experience in VAS retrieval procedures.

It is informative to briefly describe the steps involved in sounding preparation. First, the operator displays a VAS visible, IR window, or water vapor image on a video monitor. The overall region for sounding calculations is then outlined. The operator may then focus on magnified images of the region of interest. He also prepares the "first guess" soundings and surface data which will be utilized by the retrieval algorithm. The solution for the temperature and moisture profiles is not unique. Thus, the "first guess" information is used as an initial sounding to which details are added by the algorithm. Climatologically-derived mean profiles can be used for the guess. However, the usual procedure, and the one used here, is to employ a National Meteorological Center (NMC) 12 h forecast. In the current case, this forecast was valid at 1200 GMT 21 July, only 1 h from the initial VAS sounding time. Calculated and edited VAS soundings are then used as first guesses for retrievals at the subsequent times. Smith (1983) noted that middle and lower tropospheric temperatures are relatively independent of the "first guess" data.

Given the "first guess" information, the VAS soundings of temperature and moisture are then calculated automatically at the desired horizontal resolution. As many as 25 fields of view, encompassing a geographical area of approximately 75 km width, are considered for each retrieval. Cloudy fields of view are removed from the original set of 25, and no soundings are created in extremely cloudy regions. Once the objectively produced soundings are created, the operator may desire a closer data separation in certain regions, e.g., areas of strong gradients or in locations that are missed during the automated procedure. This is accomplished by instructing the computer to produce additional soundings at the specified locations.

The final step is to edit the soundings. Smith (1983) noted that presently there are no automated checks for retrieval quality. Instead, manual editing is performed by using the McIDAS. The operator views patterns of geopotential height, temperature, thickness, and thermal wind from the just retrieved VAS profiles. Soundings which appear inconsistent when compared to the others can be recognized and deleted as necessary. Edited sounding sets prepared in this manner were then sent to Saint Louis University on magnetic tape for further processing.

c. Editing at Saint Louis University

The VAS retrievals underwent a second round of editing at Saint Louis University. Our goal was to locate any unreasonable gradients or other anomalous features that had been missed originally. In addition, it was desirable to obtain a working feeling for the data which would be useful in estimating the smallest wavelength at which VAS data provide meaningful information. Koch *et al.* (1983) have noted that there is still uncertainty over this issue.

As part of our editing procedures, computer plots of constant pressure maps were made at 850, 700, 500, 300, 200, and 100 mb. The basic parameters that were plotted were geopotential height, temperature, and dewpoint. Derived parameters included precipitable water for the layers surface-700 mb, 700-500 mb, 500-300 mb, and surface-300 mb, and thickness for the layers 850-500 mb and 500-300 mb. The data for each map were then hand analyzed and exhaustively scrutinized. It should be emphasized that these analyses were performed prior to gridding. Standard subjective meteorological considerations were used to isolate faulty retrievals. These included vertical stacking, time continuity, and appropriateness of gradients. In addition, cloud contamination was investigated by relating sounding locations to cloud cover as deduced from visible and IR imagery. Questionable data at one pressure level or for one parameter usually meant similar difficulties at other levels and/or with other parame-

ters. After lengthy discussions among three experienced analysts, final decisions about editing were made. Although relatively few retrievals were eliminated, it was nonetheless a very instructive procedure.

d. Objective analysis

The decision was made to focus on the central one-third of the United States. This region, along with the locations of the edited sounding sets, is shown in Fig. 2. The convective outbreak occurred in the middle Mississippi River Valley; thus, it is near the center of the region.

In selecting the grid interval and response characteristics for the objective analysis that followed, consideration was given to the procedures of Koch *et al.* (1983). Table 4 gives the number of VAS soundings (after editing) that were contained within the analysis region at each time (Fig. 2). In relatively clear areas, the retrievals were spaced at intervals of approximately 110 km; however, because of cloud cover over certain locations, the separation was not uniform. Therefore, an additional parameter, the "random data spacing" was calculated (Koch *et al.*, 1983). It describes what the average data spacing would be inside an area if the observations were uniformly distributed within. Table 4 shows that the random spacing is always greater than that in clear areas alone (110 km). Thus, the data are clustered, especially at the 1100 GMT observation time.

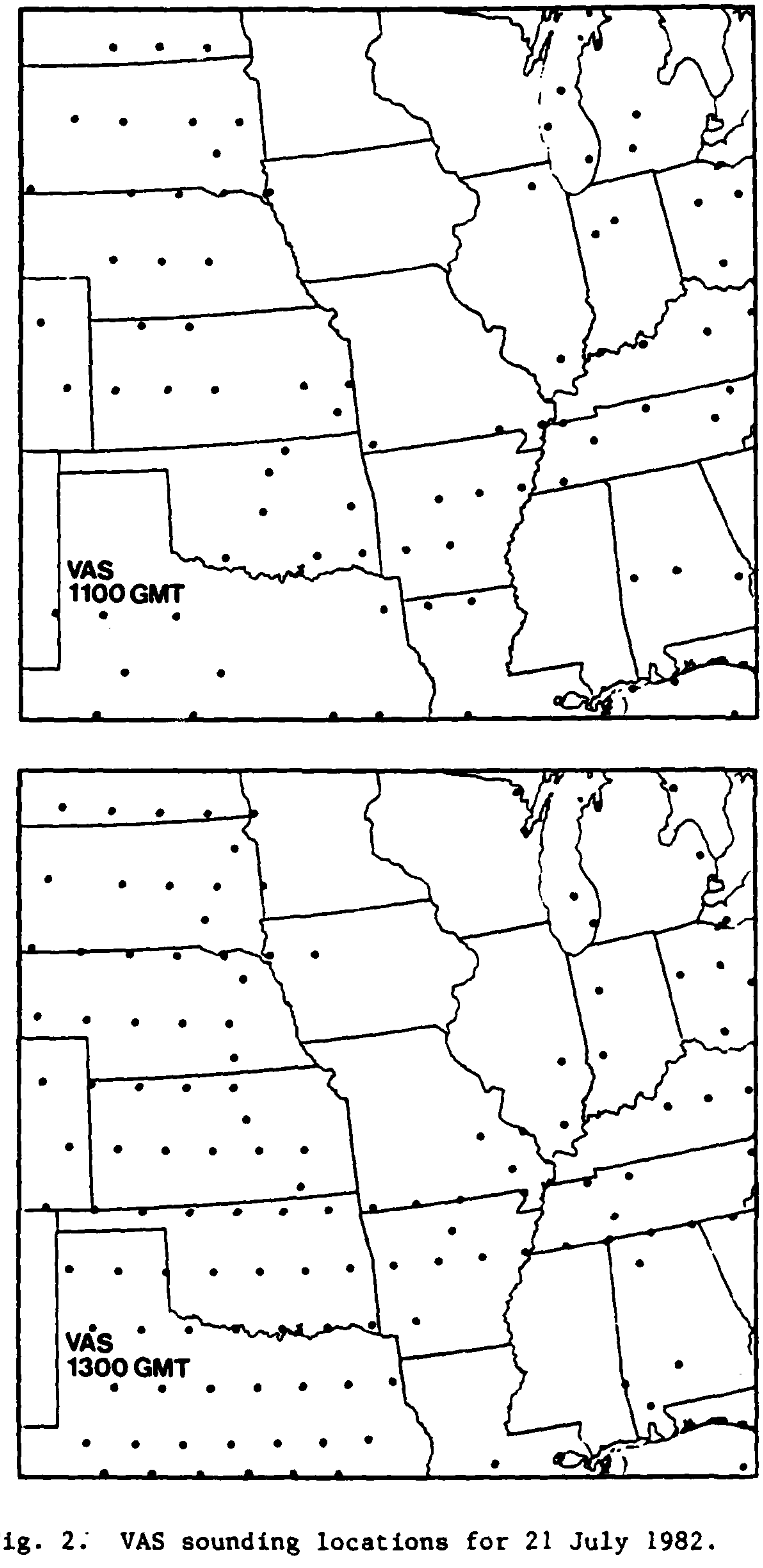
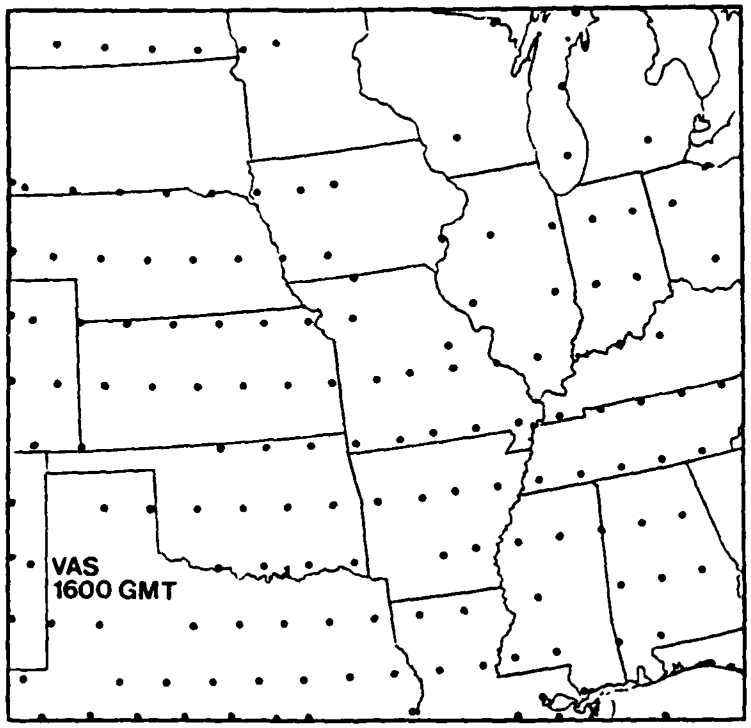



Fig. 2. VAS sounding locations for 21 July 1982.



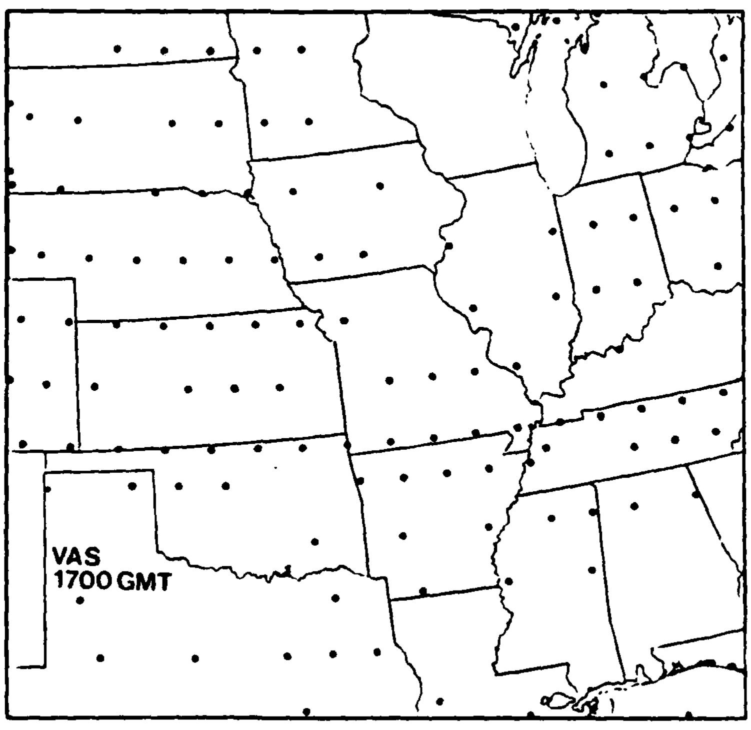
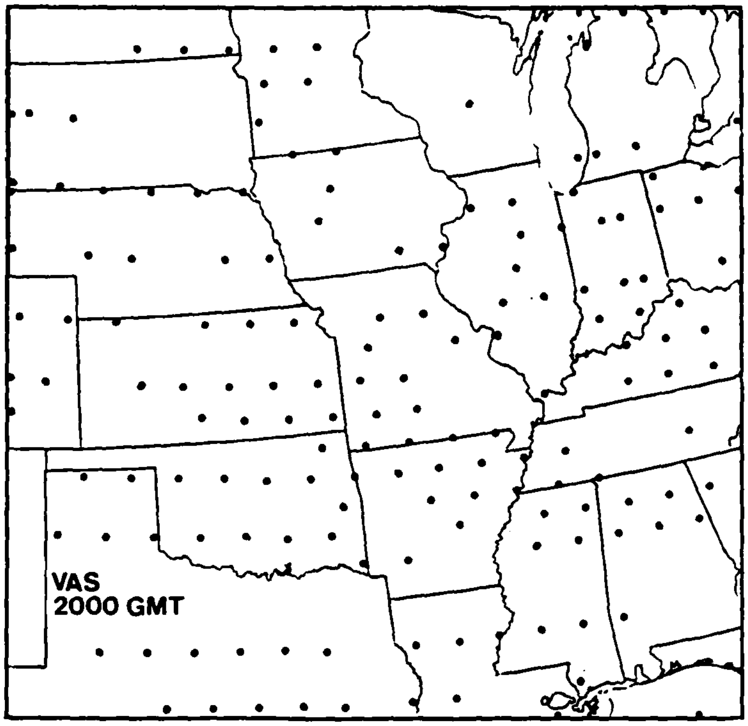




Fig. 2. Continued.



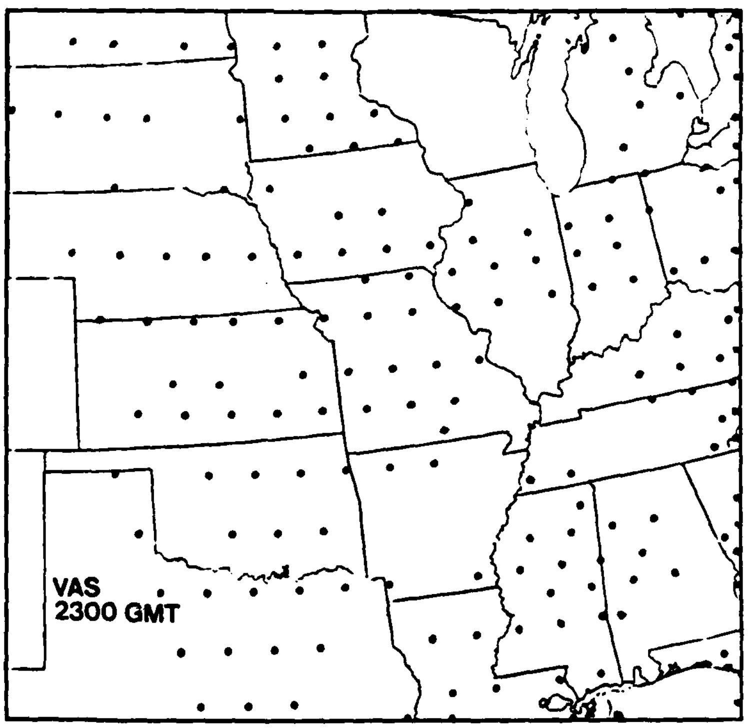




Fig. 2. Continued.

Table 4. Number of soundings after editing within the computational domain. Their separation, if uniformly distributed, is also shown.

| Sounding Time (GMT) | Number of soundings | Sounding separation (km) | Random data spacing (km) |
|---|---|---|---|
| 1100 | 81 | 110 | 245.9 |
| 1300 | 127 | 110 | 191.6 |
| 1600 | 155 | 110 | 171.8 |
| 1700 | 120 | 110 | 197.6 |
| 2000 | 157 | 110 | 170.6 |
| 2300 | 170 | 110 | 163.4 |

Based on considerations from sampling theory, a grid interval of one-half to one-third the station separation is selected when the data are uniformly spaced and when one has high confidence in them. In the current case, however, the data were highly clustered. Also, as noted earlier, the smallest scale at which the VAS soundings contain meaningful information is unknown. Therefore, it was considered inappropriate to utilize a fine scale grid mesh. Instead, the VAS soundings were treated as a meso $\alpha$-scale data source, and a grid length of 127 km was employed (see Fig. 2). This is identical to that used on the special mesoscale rawinsonde data of 10-11 April 1979 (AVE-SESAME I) by Fuelberg and Jedlovec (1982).

Objective analysis is a widely used procedure on satellite-derived soundings (e.g., Chesters et al., 1982; Jedlovec, 1984; Koch et al., 1983; Moyer et al., 1978; Petersen and Horn, 1977). One major purpose is to remove small scale detail. These features may be meteorologically important, but on too small a scale to be consistently resolved. On the other hand, they may be due to errors attributable to the retrieval procedures (e.g., cloud contamination). A second goal of objective analysis is to place the randomly spaced data onto an equally spaced grid in order to facilitate the calculation of derived parameters. Limitations of objective analysis techniques include computational difficulties such as truncation errors. In addition, most analysis procedures assume a uniform data density; thus, undesirable patterns may be

produced in data gaps and along the edges of the domain.

This investigation utilized the Barnes et al. (1973) objective analysis procedure. After several response curves were investigated, it was decided to use the profile shown in Fig. 3 which is based on the constants $\gamma=0.4$ and $4c=50{,}000$. This response is consistent with that of a meso $\alpha$-scale data source. For example, amplitudes of wavelengths of 500 km are retained at approximately 60% of the original signal level. Fig. 4 shows objective and hand analyses of geopotential height at the 850 and 200 mb levels for 1600 and 1700 GMT 21 July. One should note that meso $\alpha$-scale features are retained whereas shorter wavelength features are greatly filtered. The possible creation of meso $\beta$-scale analyses is a potential topic for future research.

The Barnes et al. (1973) objective analysis also was used on rawinsonde data at the bracketing times. However, a different response curve was employed (Fig. 3). The effect is that more horizontal detail is retrieved from the VAS soundings than the rawinsonde data.

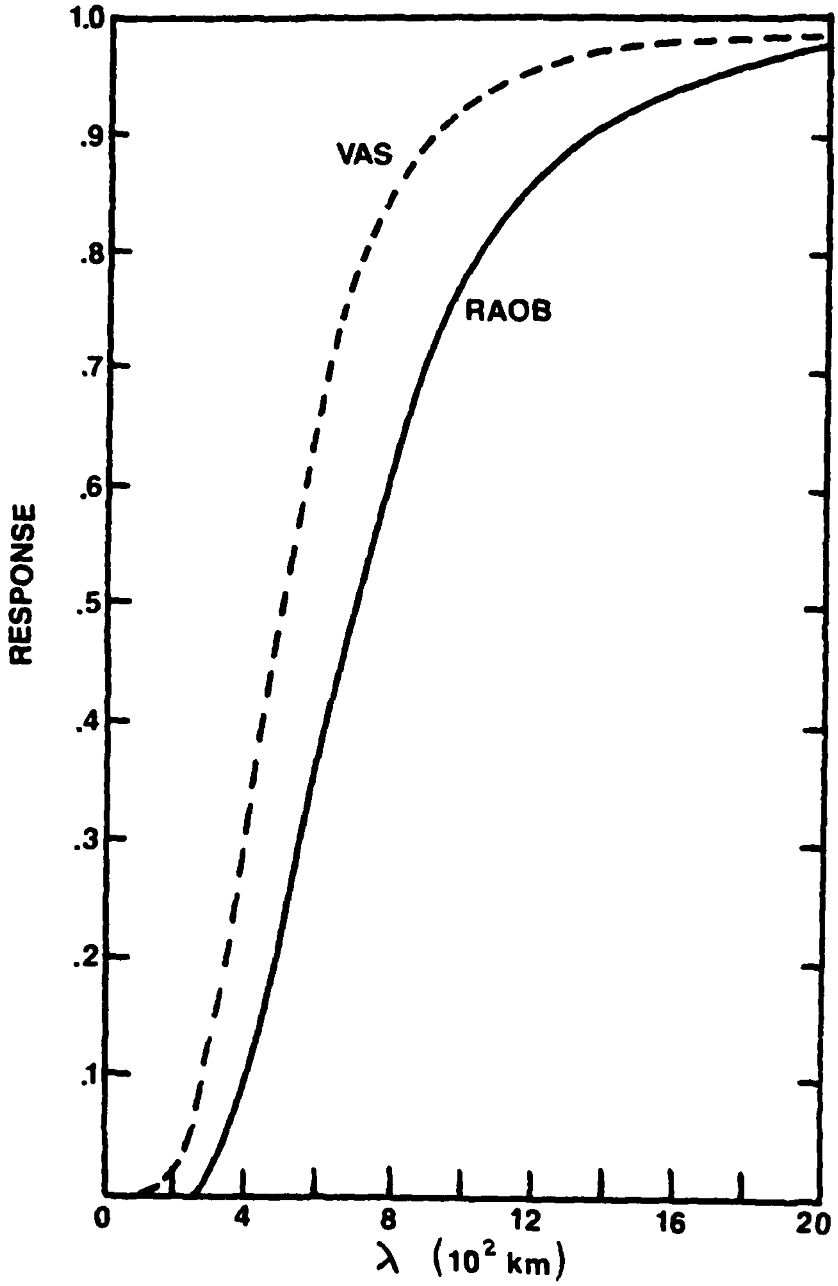



Fig. 3. Response curves used to objectively analyze the VAS and rawinsonde soundings.

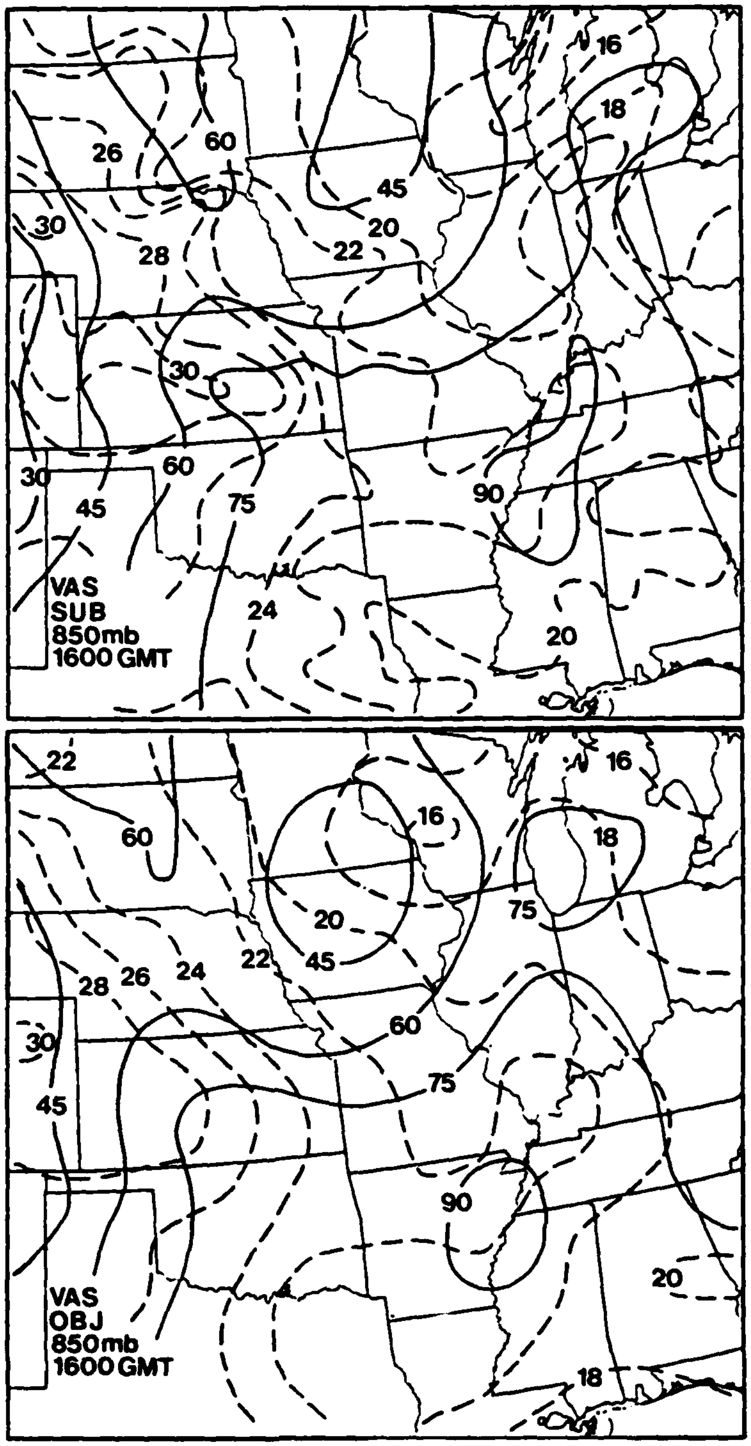



Fig. 4. VAS subjective (SUB) and objective (OBJ) analyses at 850 and 200 mb for 1600 and 1700 GMT 21 July. Heights are solid while temperatures are dashed. At 850 mb, 75 represents 1575 m; whereas at 200 mb, 48 represents 12,480 m.

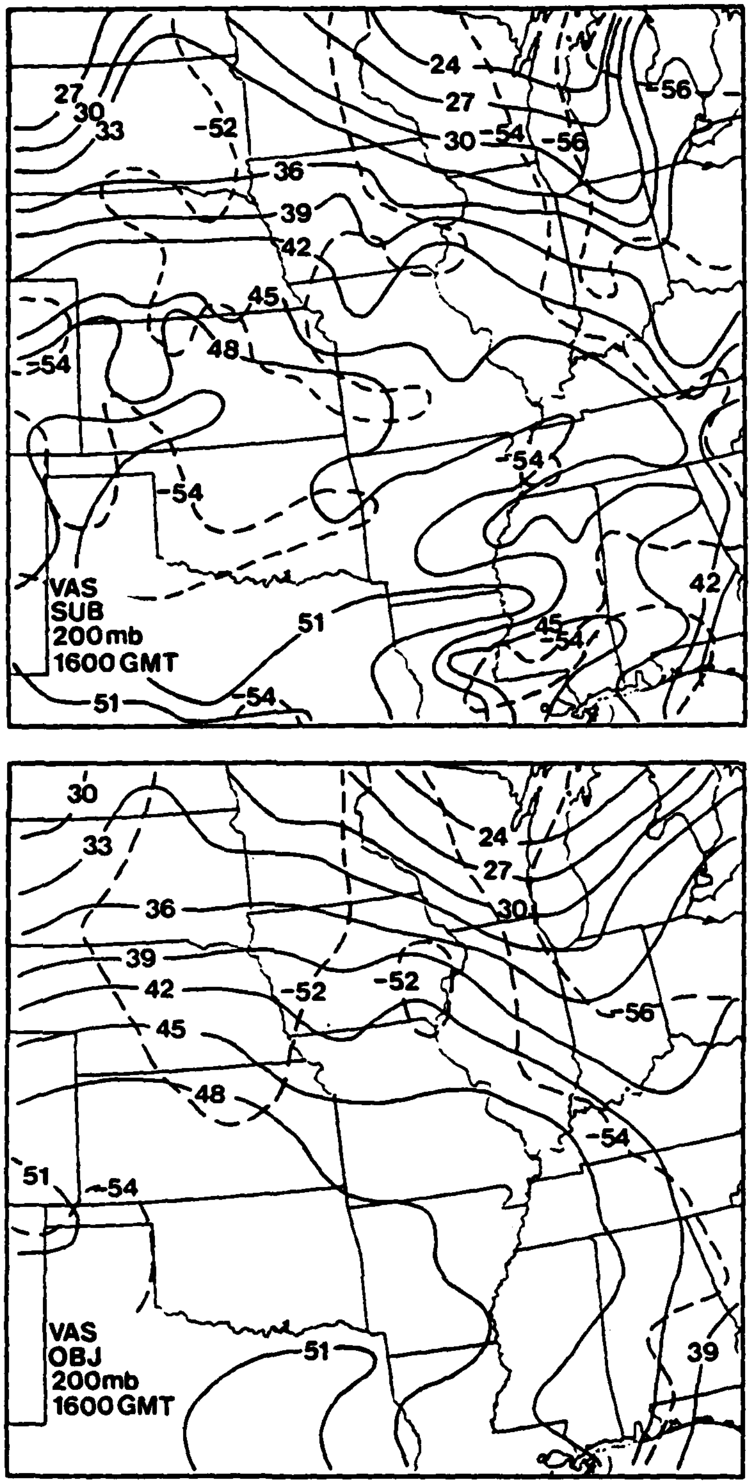



Fig. 4. Continued.

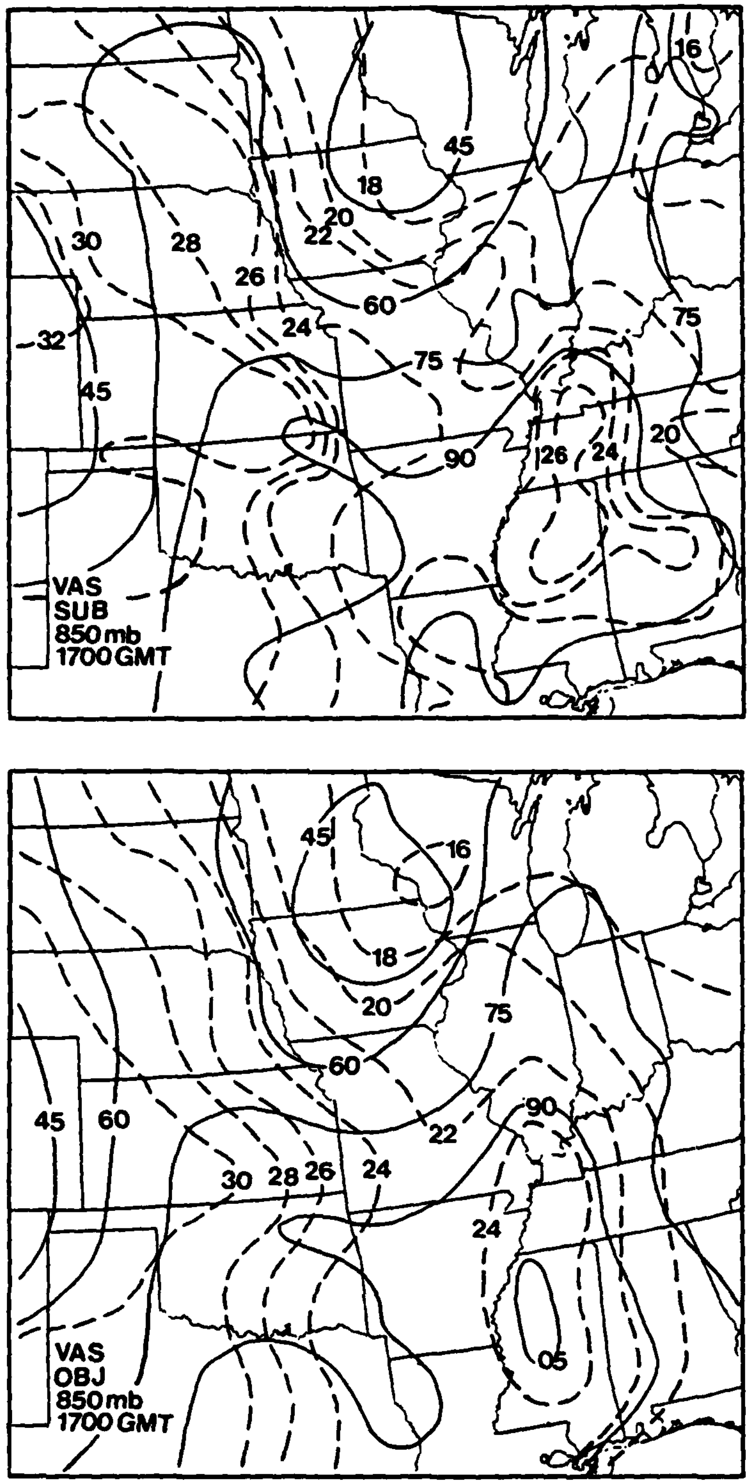
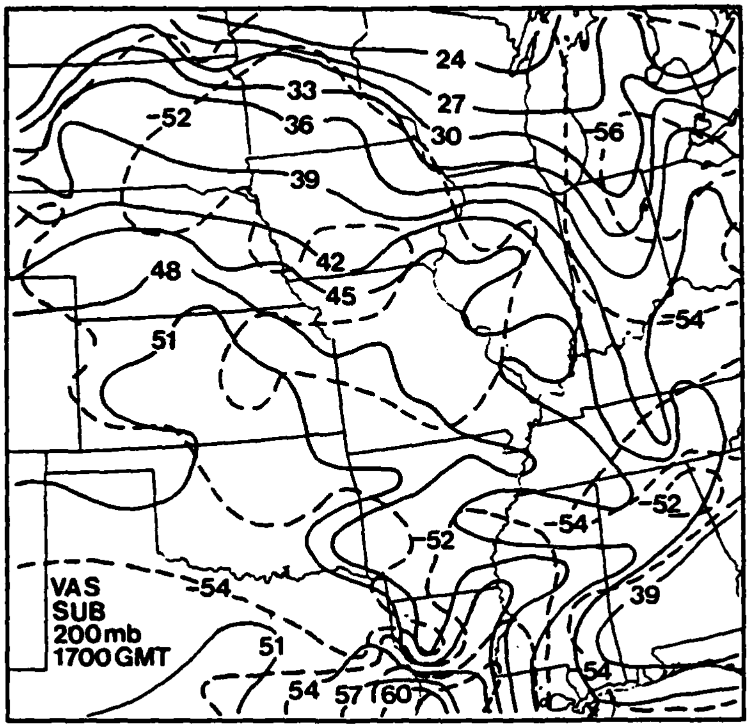



Fig. 4. Continued.



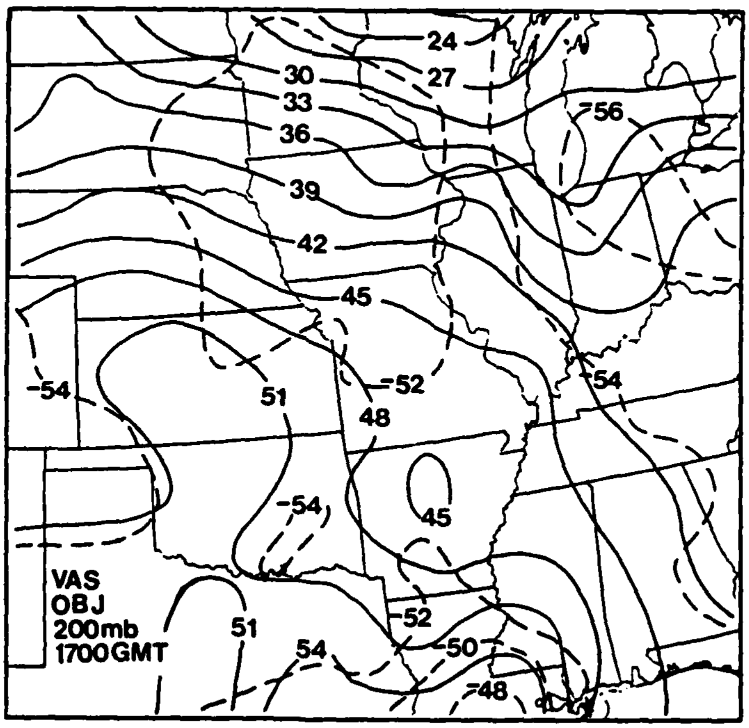




Fig. 4. Continued.

## 3. WEATHER CONDITIONS

Although 21 July 1982 was not an especially baroclinic situation, it nevertheless was a period of significant convection. During the 24 h study period beginning at 1200 GMT 21 July, one tornado, two cases of large hail, and fifteen cases of damaging winds were documented within the grid network. Additional severe weather events occurred after the period of study in association with the convection in progress at 2300 GMT.

Synoptic conditions at the beginning of the period (1200 GMT 21 July) are shown in Fig. 5. At the surface, a cold front extended from the east coast to Missouri. From there it became stationary, winding through Kansas to a low in Colorado. The temperature contrast (Fig. 6) across the front was persistently between 6 to 8 $^{\circ}C$ over Missouri and Illinois. Dewpoints (not shown) along the Gulf Coast ranged from 20 to 22 $^{\circ}C$ but were near 10 to 12 $^{\circ}C$ over the Great Lakes States. A second cold front curved through Minnesota, Nebraska, and South Dakota. Conditions in the middle troposphere (Fig. 5) were dominated by a trough extending from Minnesota to Kansas. An anticyclone stretched from Colorado through the middle Mississippi River Valley. In the upper troposphere (not shown), winds were weak, and the jet stream was poorly defined.

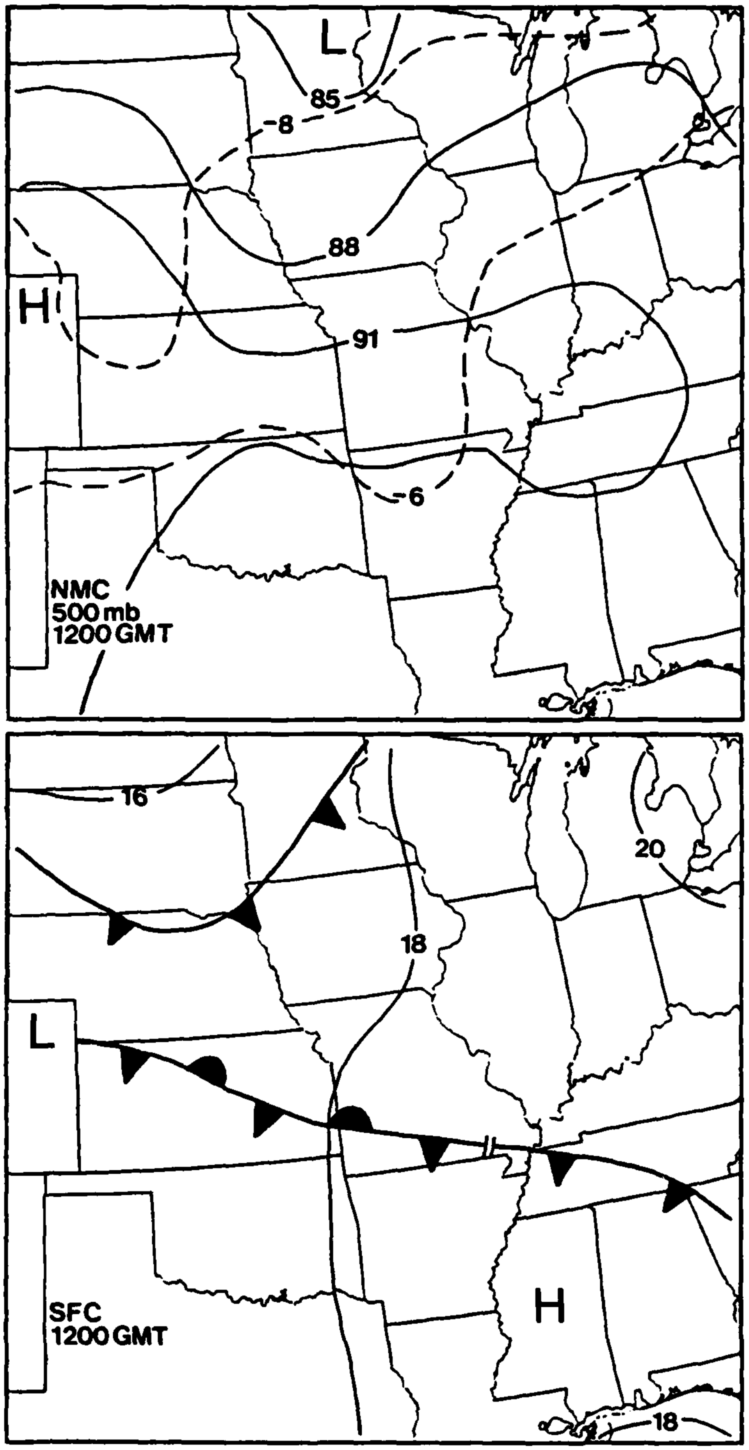
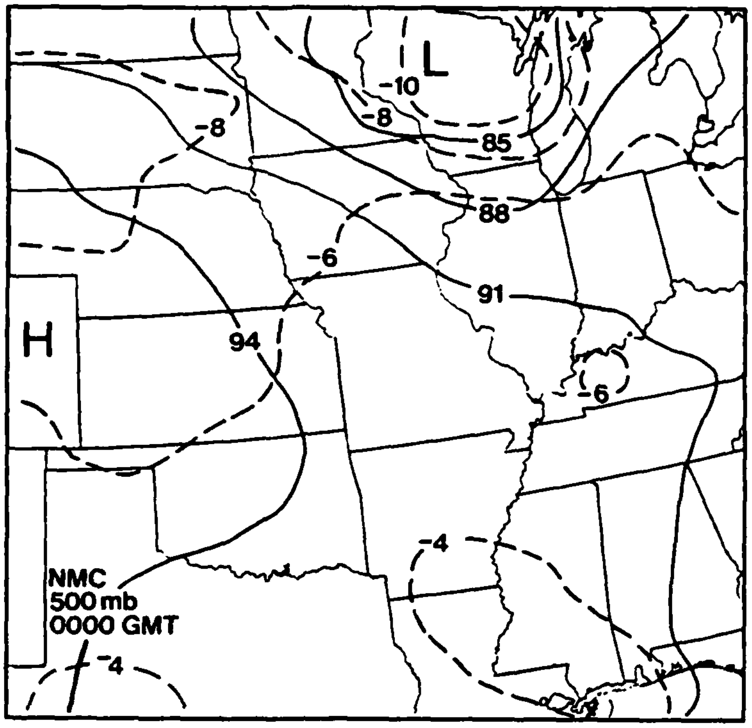



Fig. 5. Surface and 500 mb National Meteorological Center (NMC) analyses for 1200 GMT 21 July and 0000 GMT 22 July. Heights and sea level pressures are solid while temperatures are dashed. At the surface, 16 represents 1016 mb; whereas at 500 mb, 91 represents 5,910 m.



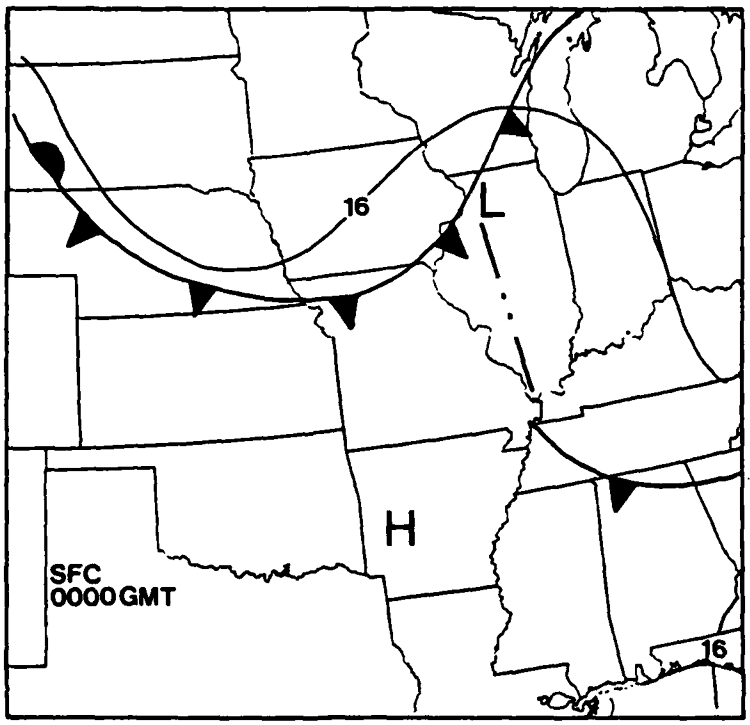




Fig. 5. Continued.

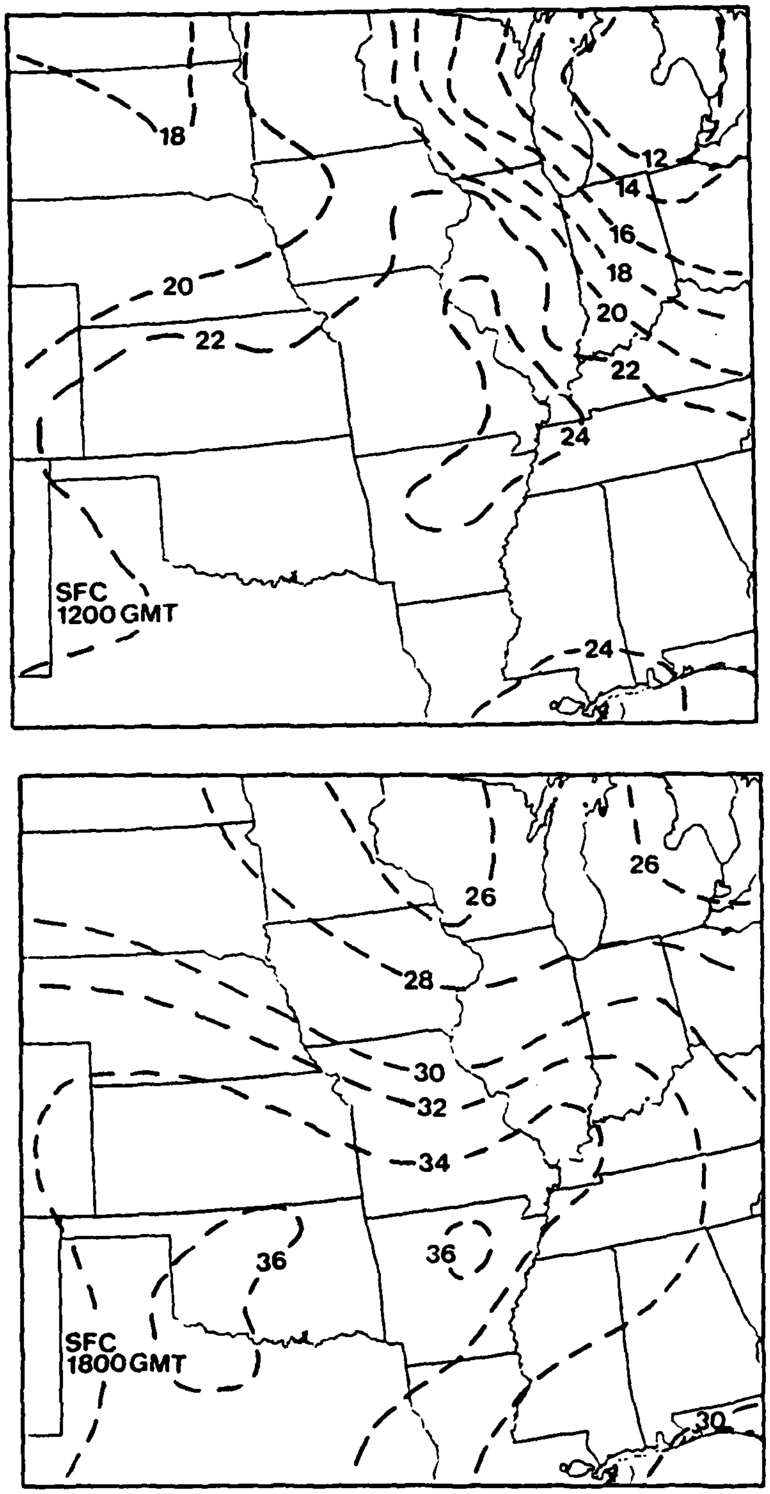



Fig. 6. Surface temperatures for 1200 GMT 21 July, 1800 GMT 21 July, and 0000 GMT 22 July.

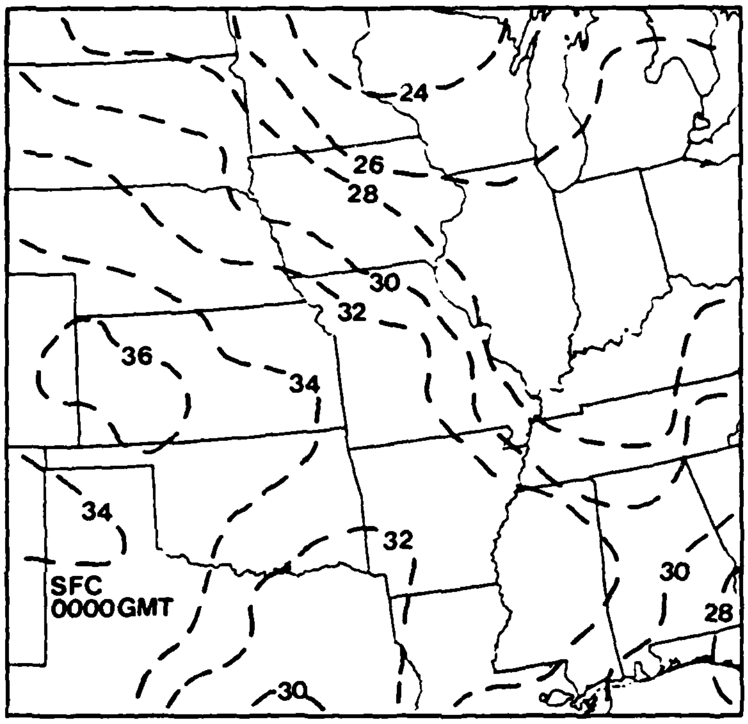



Fig. 6. Continued.

Precipitation at 1135 GMT 21 July was occurring along and ahead of the cold front in Minnesota and Iowa and also to the north of the stationary front in Missouri. Nebraska, and Kansas (see Fig. 7). Echo tops of thunderstorms reached 13.3 km (44,000 ft). These storms had formed approximately 12 h earlier and had remained nearly stationary throughout the day. They had mostly dissipated by 1735 GMT (Fig. 7).

A new area of storms developed over the middle Mississippi River Valley near 1735 GMT (Figs. 7-8). The goal of this study is to utilize VAS soundings to investigate atmospheric conditions leading to the formation of this convection. Before doing so, however, it is useful to describe large scale features associated with the outbreak, as well as the evolution of the storms themselves. First, it should be noted that the region was quite unstable. Based on rawinsonde soundings at 1200 GMT, values of the Lifted Index (LI) were approximately -5. Also, since values of precipitable water were near 40-50 mm, the area had an ample supply of water vapor. Thus, suitable triggering mechanisms could produce the convection that began near 1735 GMT.

There were several sources for the upward motion that released the instability. One area of storms extended from southern Illinois through northern Alabama, and it appears to be related to the warm front over that region. A second area extended through Arkansas, and based upon radar summaries together with hourly visible GOES imagery, this convection

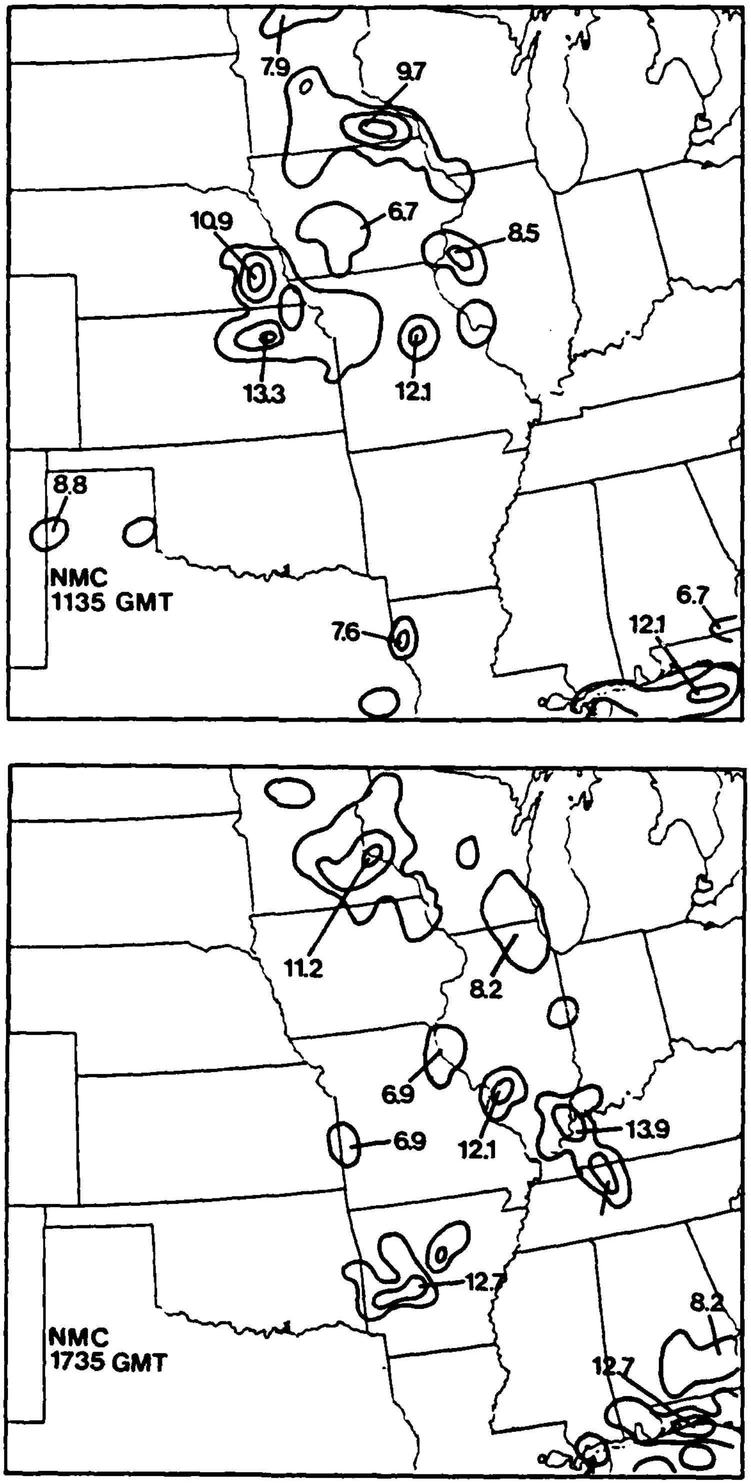



Fig. 7. NMC radar summaries with echo tops in km.

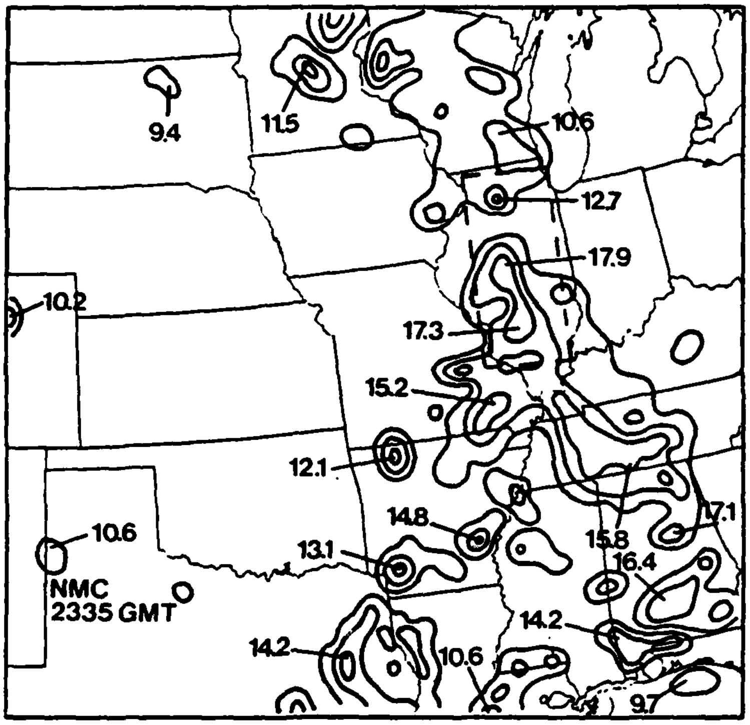
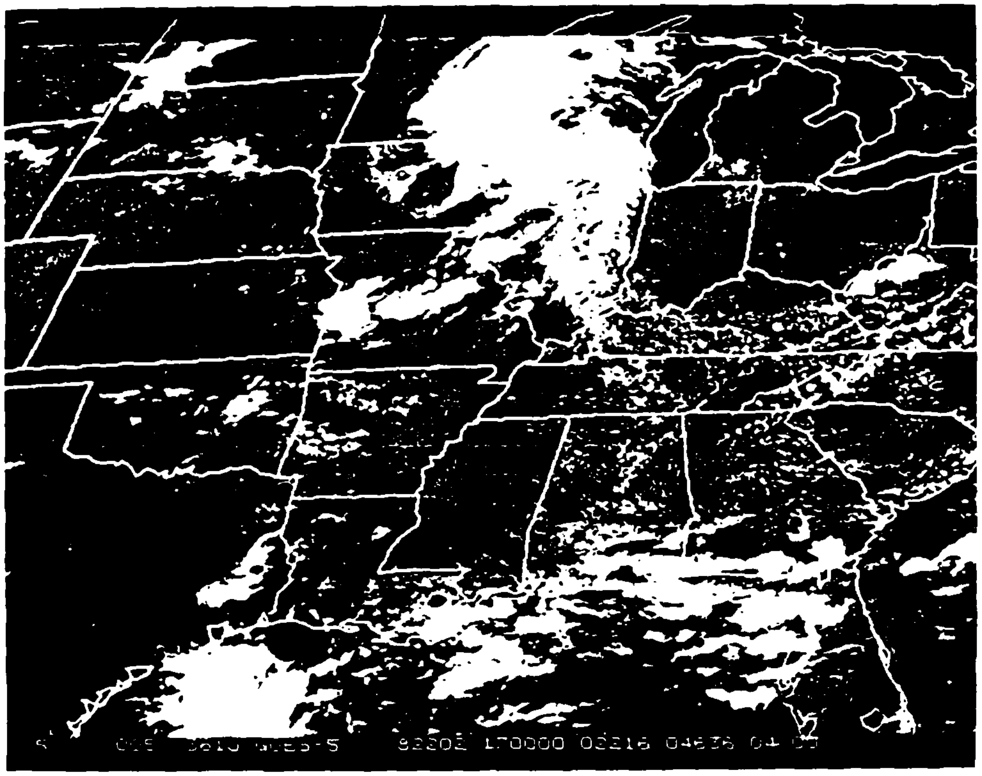
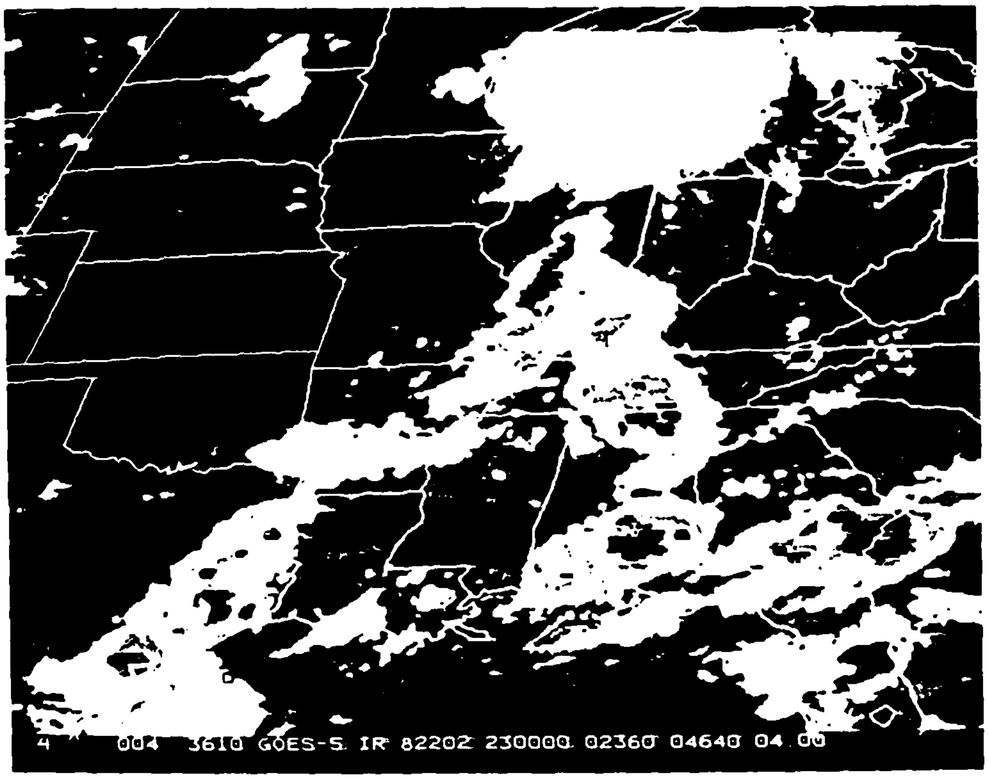



Fig. 7. Continued.



(a)

Fig. 8. GOES visible image at 1700 GMT 21 July (a) and GOES IR image at 2000 GMT 21 July (b).




(b)

Fig. 8. Continued.

appears to have been initiated by a thunderstorm outflow boundary originating to the north. A third area of storms was located over Missouri. Here, large scale ascent due to the middle tropospheric trough advancing into the region (Fig. 5), together with a possible second storm outflow boundary, appear to have been the triggering mechanisms. Finally, afternoon surface heating was the major cause for a fourth area of storms along the Gulf Coast States. However, this factor most likely contributed to all other areas of convection as well. Fig. 6 shows that the middle Mississippi River Valley was relatively warm even in the early morning. By the afternoon, surface temperatures were in excess of 30 °C over a large portion of the study region. At the time of greatest storm intensity and area coverage (2335 GMT, Figs. 7-8) the convection was affecting Illinois, Missouri, Kentucky, Tennessee, Arkansas, and all of the Gulf Coast States. A severe weather watch had been issued for most of Illinois where echo tops reached 17.9 km (59,000 ft). Additional details about the outbreak, obtained from the VAS soundings, will be discussed thoroughly in the Results section.

Finally, by the end of the study period, 0000 GMT 22 July (Fig. 5), the cold front through the southeast had moved little, and NMC had omitted the stationary segment. The cold front over the northwest section of the region had gradually moved southeastward, stretching from Wisconsin to Missouri. It became stationary through Nebraska. At 500 mb, the trough had advanced

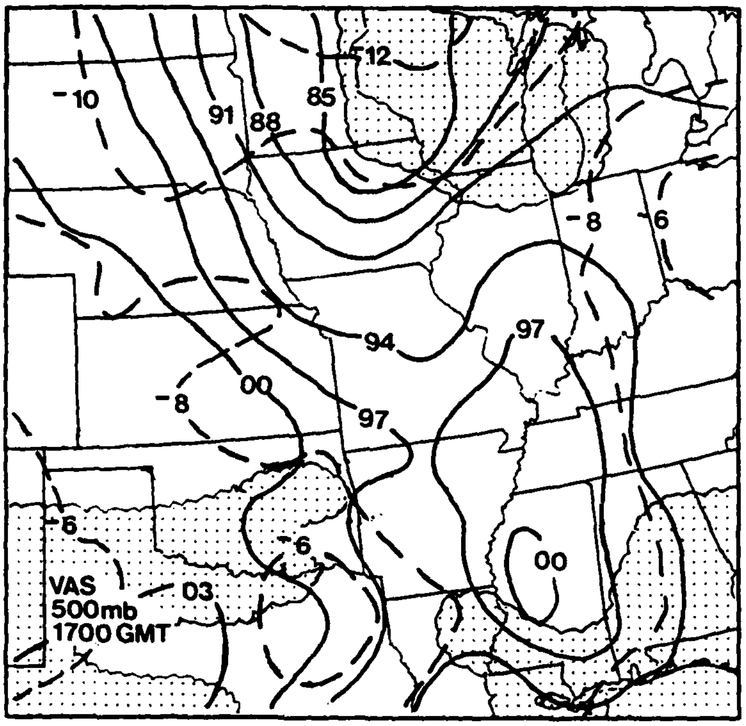
eastward, being aligned on an axis through Illinois. Higher values of height had developed throughout the entire southern half of the region.

## 4. RESULTS

The convective outbreak being studied began at approximately 1735 GMT 21 July. This section will concentrate on atmospheric changes between the 1200 GMT rawinsonde observations and the 1700 GMT VAS soundings. Variations revealed by the 2000 and 2300 GMT VAS retrievals also will be described. For the sake of brevity, conditions in the middle troposphere (500 mb) will be emphasized; however, other levels will be described when appropriate. There will be no discussions of the 1100 and 1300 GMT VAS soundings due to excessive regions of cloud cover (see Fig. 2).

### a. Geopotential height

At 500 mb, the major height feature is the development of a mesoscale anticyclone centered over Mississippi (Fig. 9). Values of geopotential height in the area increase at a steady rate after 1100 GMT. resulting in a cutoff high by 1700 GMT. It should be noted that this feature does not occur in a data gap (see Fig. 2) and is not associated with excessive cloud cover (see Fig. 8). Between 1600 (not shown) to 1700 GMT, values increase approximately 25 m over the region. At 1700 GMT, the location of the high coincides with most of the storm area (Fig. 7). Afterwards, heights fall at a rate of approximately 10 m $h^{-1}$, resulting in the dissipation of the anticyclone. One should note the agreement



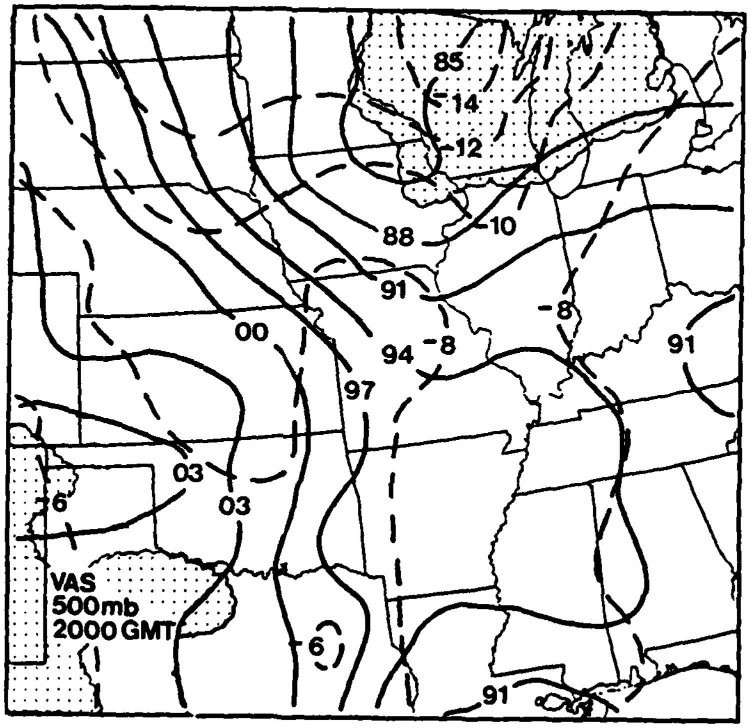




Fig. 9. VAS-derived 500 mb analyses at 1700, 2000, and 2300 GMT. Heights are solid, temperatures are dashed, and stipling indicates data gaps. The height 94 represents 5940 m.

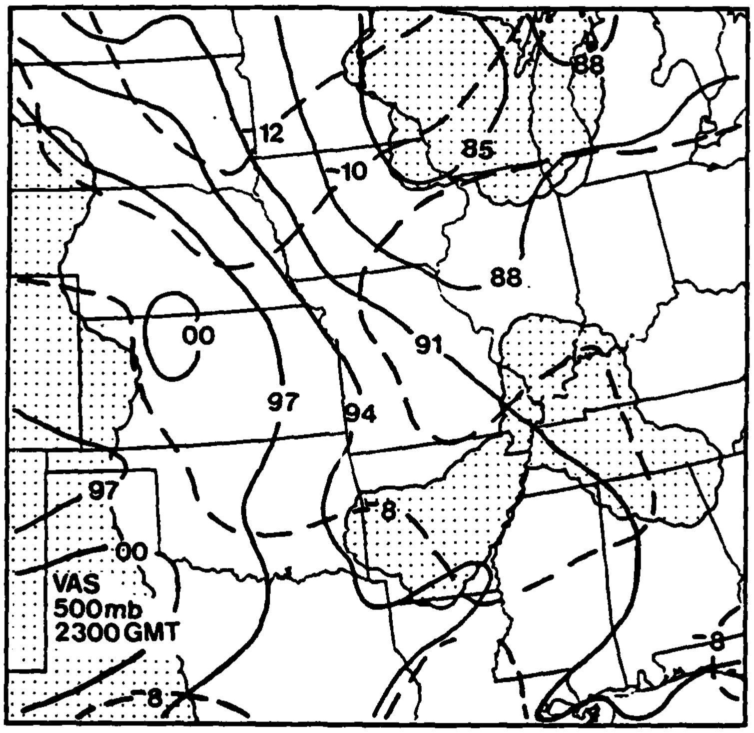



Fig. 9. Continued.

between VAS-derived patterns at 2300 GMT (Fig. 9) and the rawinsonde-derived patterns at 0000 GMT (Fig. 5). Also it is significant that the evolution of the anticyclone is entirely missed by the standard 12 h rawinsonde releases.

VAS data also provide excellent movement for other height features. The continuity of the trough over the Midwest should be noted. Based on the rawinsonde data, the trough axis is over western Iowa at 1200 GMT (Fig. 5), but the VAS retrievals indicate movement into eastern Iowa by 1700 GMT (Fig. 9). It is located over Illinois at 2300 GMT, thereby agreeing favorably with the NMC analysis at 0000 GMT 22 July (Fig. 5). VAS retrievals were not possible over the area near Wisconsin at all three times. Yet, in spite of this difficulty, the continuity appears quite reasonable. The lowest contour value for the rawinsonde analyses at 1200 and 0000 GMT and the VAS analyses between 1700 and 2300 GMT is 5850 m. As mentioned earlier, the eastward motion of this trough is a probable triggering mechanism leading to the convective outbreak over the middle Mississippi River Valley.

Finally, one should note the consistently higher heights over the western portion of the region (Fig. 9). Although cloud cover limits satellite soundings over western Texas, it is nonetheless apparent that this is a region of major anticyclonic flow.

b. Temperature

At 1200 GMT 21 July, the rawinsonde data (Fig. 5) indicate that a cold tongue is located over Nebraska, west of the height trough. The VAS-derived patterns later in the day (Fig. 9) continue these relative locations. The cold tongue gradually moves eastward during the afternoon, lagging the height pattern. By comparing the 2300 GMT VAS-derived patterns with the 0000 GMT NMC analysis, it appears that the satellite retrievals contain a relative cold bias at this level. Nevertheless, the agreement between patterns is good.

Horizontal temperature gradients at 500 mb strengthen in the northern half of the region between 1700-2300 GMT (Fig. 9), and this is confirmed by the 0000 GMT NMC analysis (Fig. 5). The VAS retrievals show that temperatures over the middle Mississippi River Valley are relatively cool just prior to the convective outbreak. At 1.5 h before storm initiation (1600 GMT, not shown), VAS-derived temperatures over this region are around -8 $^{o}$C; however, they then fall to -9.5 $^{o}$C (Fig. 9) in only 1 h. The thickness chart for the 500-300 mb layer at 1700 GMT (Fig. 10) shows that the entire layer is relatively cool. This cooling trend obviously is not detected by the 12 h rawinsonde data. The figure also shows that the lower troposphere (850-500 mb) is relatively warm. Thus, with relatively warm temperatures near the surface (Fig. 6) and cool conditions aloft, the region apparently is less stable than the surroundings. This facet will be explored in a

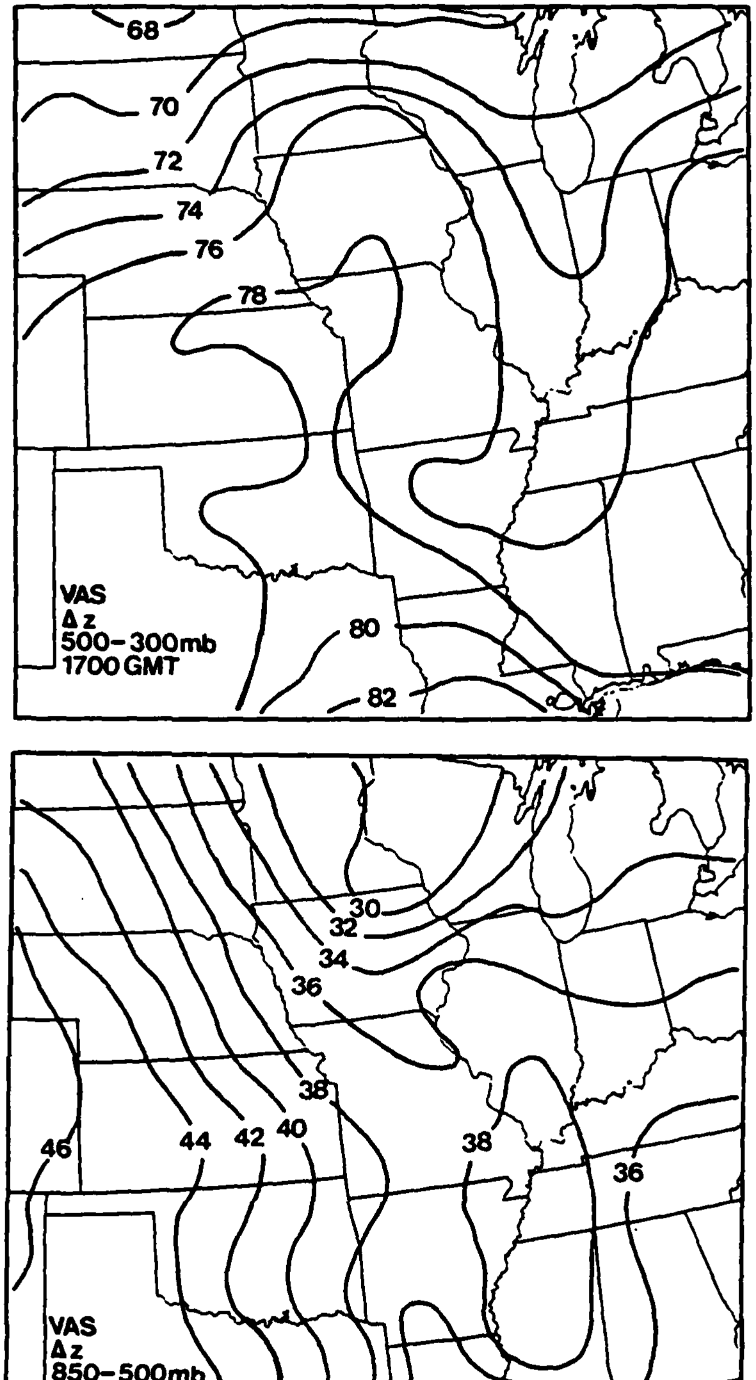



Fig. 10. VAS-derived thicknesses for the 850-500 and 500-300 mb layers at 1700 GMT 21 July. For the upper layer, 78 represents 3,780 m; whereas in the lower layer 38 represents 4,380 m.

later section of this report. Finally, warmest temperatures at 500 mb are located over the western half of the region, in the area of the major anticyclone.

c. Precipitable water

The presence of adequate water vapor is a necessary ingredient for thunderstorm formation. Precipitable water in the surface to 300 mb layer is presented to describe the humidity patterns. Horizontal analyses from the rawinsonde data are given for 1200 GMT 21 July and 0000 GMT 22 July, while VAS-derived patterns are presented for 1700, 2000, and 2300 GMT 21 July (Fig. 11).

In general, one should note that the moist and dry patterns from the VAS soundings exhibit good continuity and provide more horizontal detail than is available from the usual rawinsonde releases. Specifically, the 1200 GMT sonde data (Fig. 11) indicate a moist tongue extending from the Gulf of Mexico into the middle Mississippi River Valley. The VAS-derived patterns between 1100 to 1600 GMT (not shown) continue this feature. Minimum precipitable water from the rawinsondes (Fig. 11) and the VAS data (not shown) is located over Colorado and the Great Lakes region where values are less than 20 mm.

Between 1600 to 1700 GMT moisture content increases dramatically over the middle Mississippi River Valley (Figs. 11-12). The 1 h change of 10 mm results in values of 70-75 mm over this

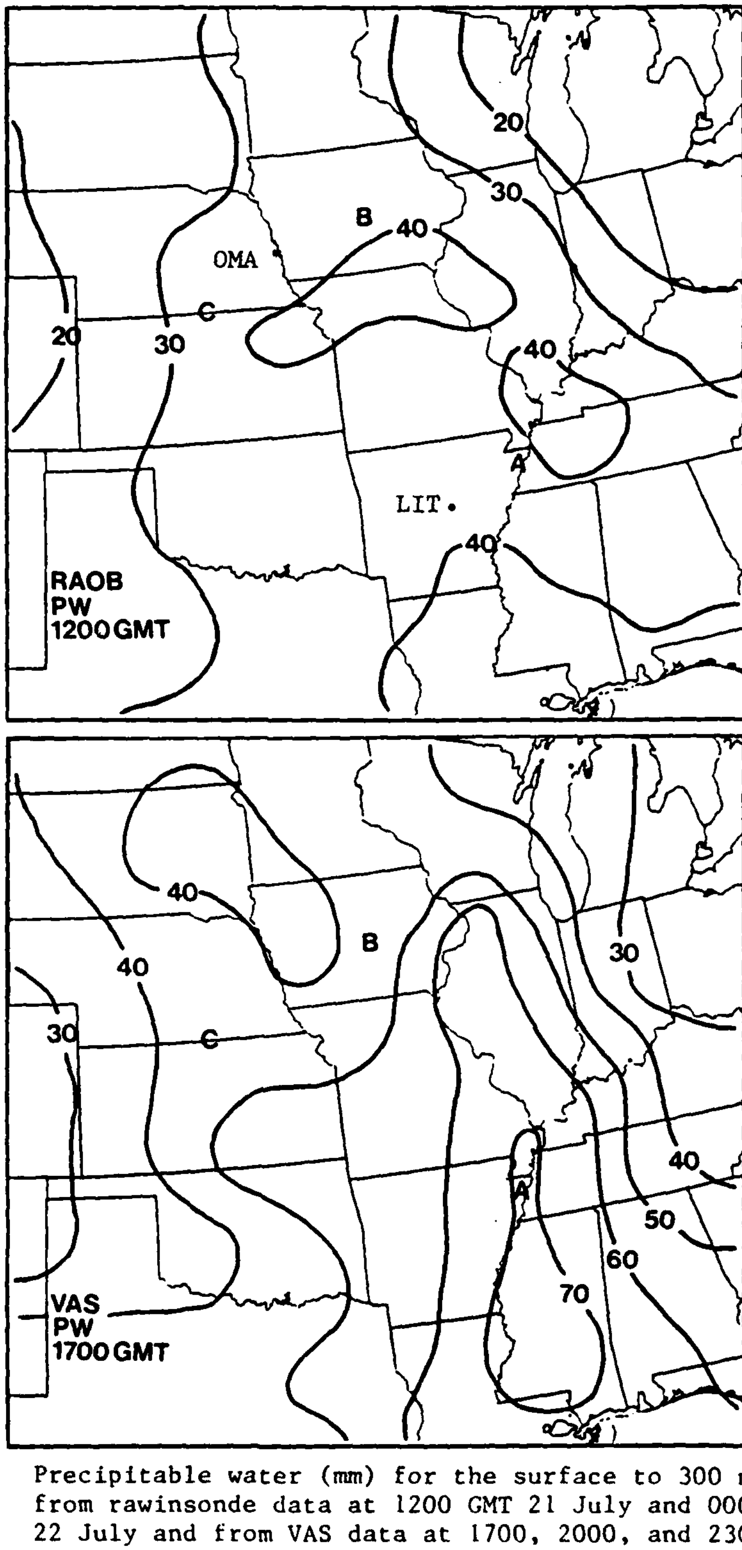
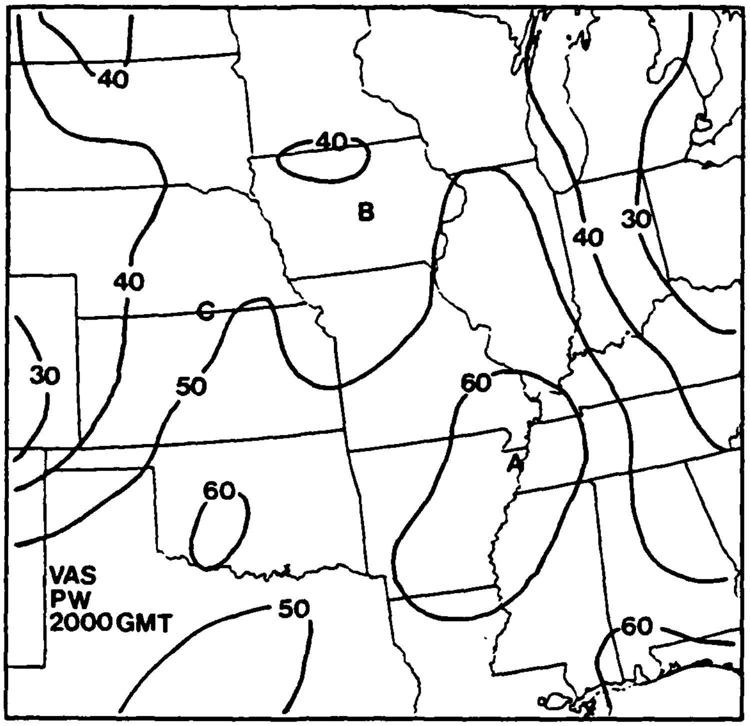



Fig. 11. Precipitable water (mm) for the surface to 300 mb layer from rawinsonde data at 1200 GMT 21 July and 0000 GMT 22 July and from VAS data at 1700, 2000, and 2300 GMT 21 July.



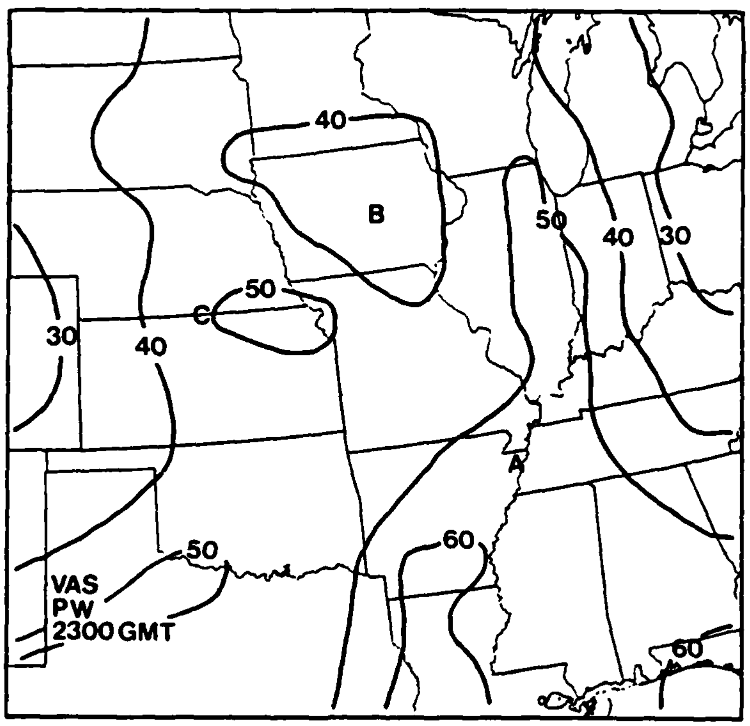




Fig. 11. Continued.

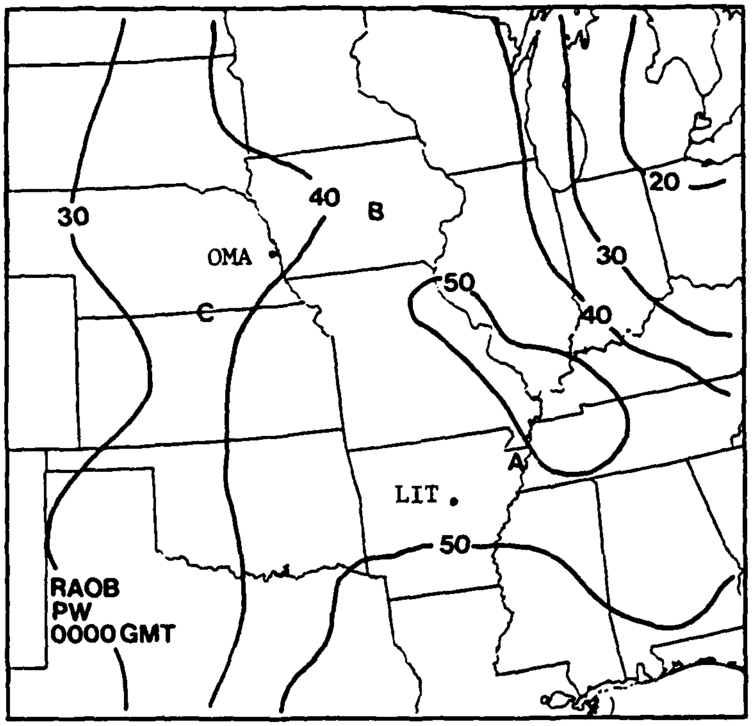



Fig. 11. Continued.

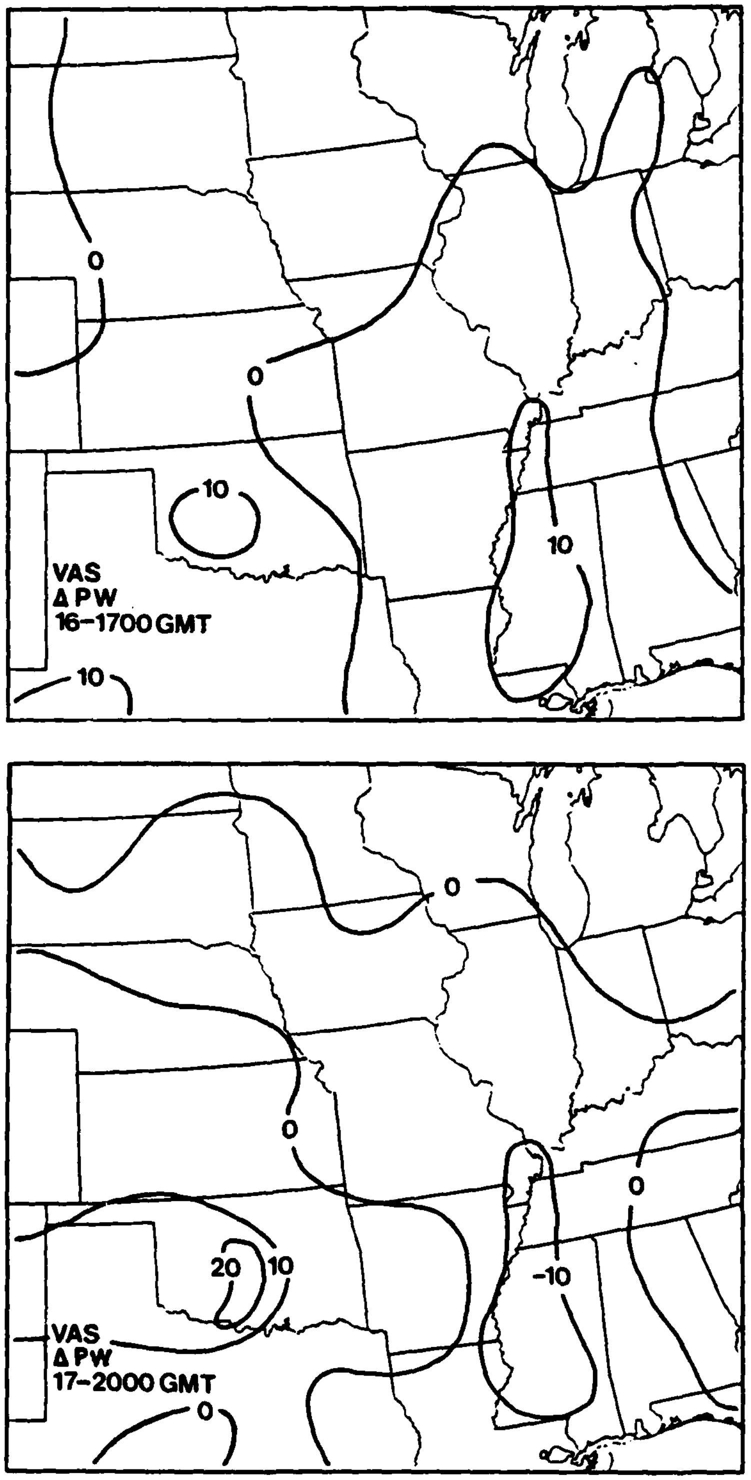



Fig. 12. Changes in precipitable water (mm) for the surface to 300 mb layer between 1600 to 1700 GMT and 1700 to 2000 GMT 21 July.

region. The increase occurs just prior to the storm outbreak beginning at 1735 GMT (see Fig. 7). Water vapor content decreases between 1700 to 2000 GMT after storm initiation. Although the humidity values appear excessive, a feature also noted by Anthony and Wade (1983), the important point is that water vapor content is increasing over this region prior to the thunderstorm outbreak. Fig. 13 shows that the impending region of convection is relatively moist, even in the upper troposphere.

Another interesting feature is the increase in humidity between 1600 to 2000 GMT over Oklahoma and the Texas panhandle (Fig. 12). The result is a secondary moist tongue over this region (Fig. 11). Although the 12 h NMC data also show a corresponding increase of precipitable water, though not a moist tongue (Fig. 11), details of its temporal development are not provided. Thus, this type of short-term information available from the VAS should be very useful in forecasting thunderstorm outbreaks. During this case, no convection is associated with the moist tongue during the 12 h study period.

## d. Stability

Stability indices are useful to the severe storm forecaster because they combine the effects of temperature and humidity at several levels into a single parameter. Three indices were computed as part of this study -- LI, K Index, and Total Totals Index. Patterns of LI were found to be similar to those of the K Index and the Total Totals Index. Thus, only results of the LI

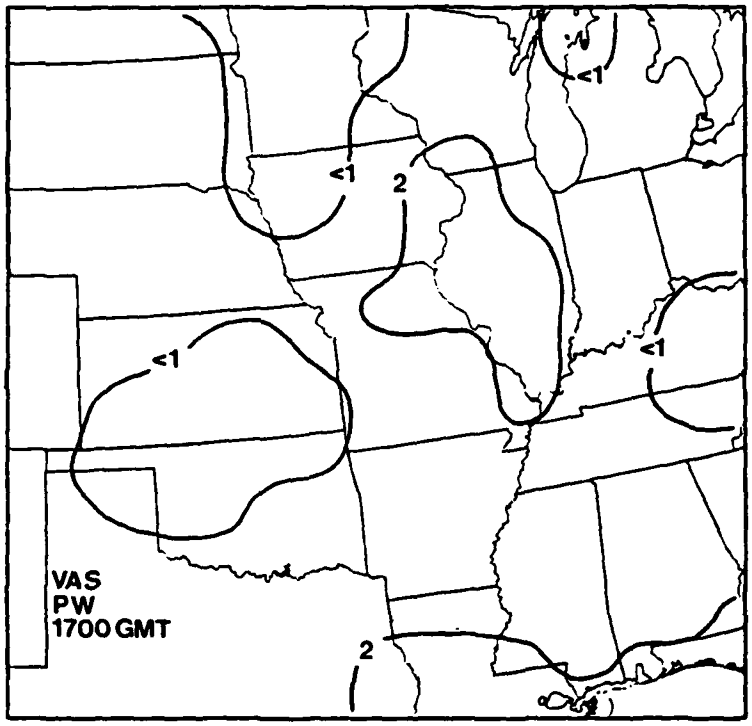



Fig. 13. VAS-derived precipitable water (mm) for the 500-300 mb layer at 1700 GMT 21 July.

are described here.

The rawinsonde data at 1200 GMT 21 July (Fig. 14) show strongly stable conditions over the northeast portion of the study region. On the other hand, conditions are much less stable over the midsection of the United States. Lowest values of the LI are -1 over the Missouri-Illinois border, and a band of near zero values stretches southward to the Gulf Coast and westward into Kansas.

One should note that VAS diagnoses the entire area as being less stable at 1700 GMT (Fig. 14) than observed by the rawinsonde data 5 h earlier. A comparison of the 2300 GMT VAS retrievals and the 0000 GMT ground based patterns indicates a similar situation. Anthony and Wade (1983) observed that VAS usually detects horizontal patterns and trends in stability, but that actual values frequently differ from the sonde-derived units. In the current case, instability appears to be overestimated by the satellite data. This is discussed further in the following paragraphs.

The VAS-derived indices between 1700 to 2300 GMT (Fig. 14) show several important stability features. At 1700 GMT, the most stable area is still over the northeast, and this continues through the end of the study period. The most unstable region at 1700 GMT is over the lower Mississippi River Valley where values reach -10. The changes in LI over this region between 1600 to 1700 GMT are as great as -4 (Fig. 15). As noted earlier, the LI values are probably too extreme, but the trend toward decreasing

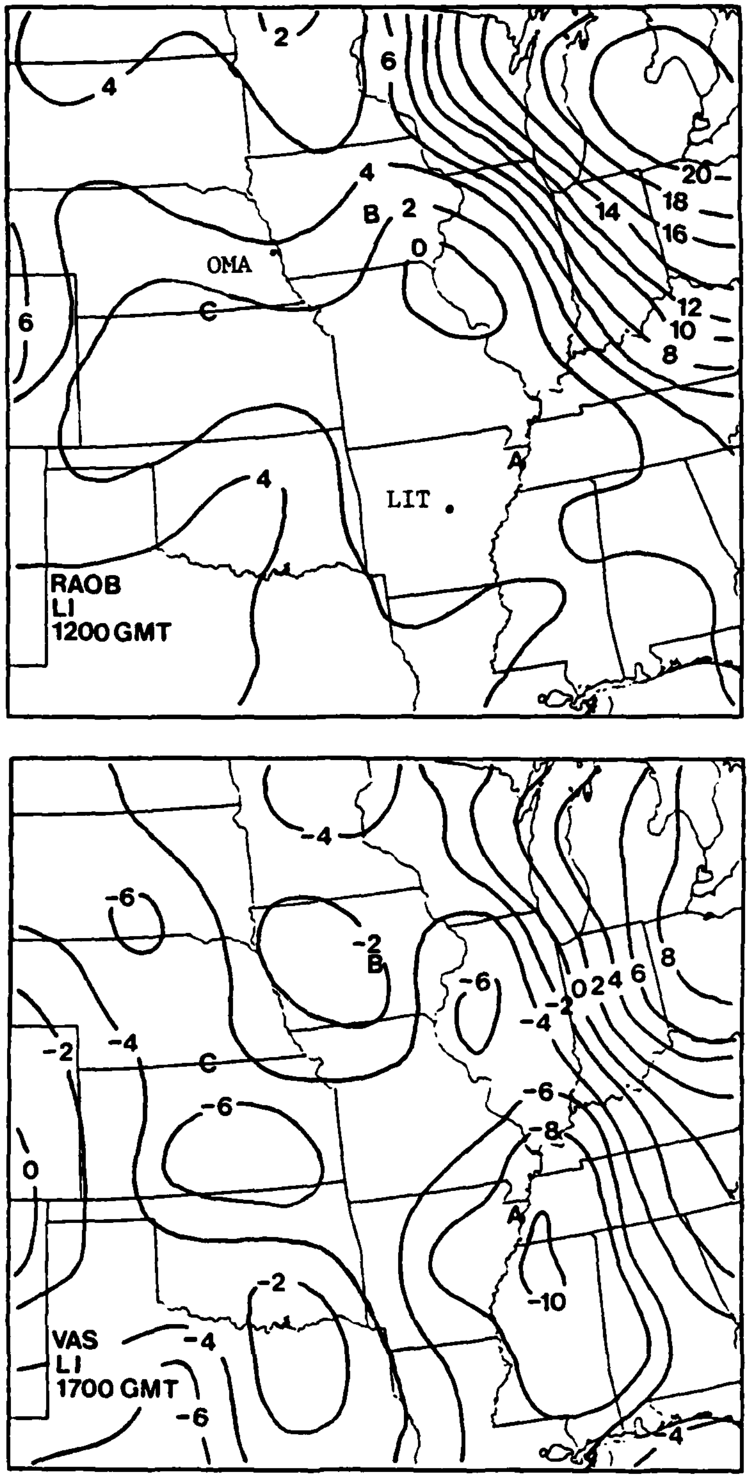
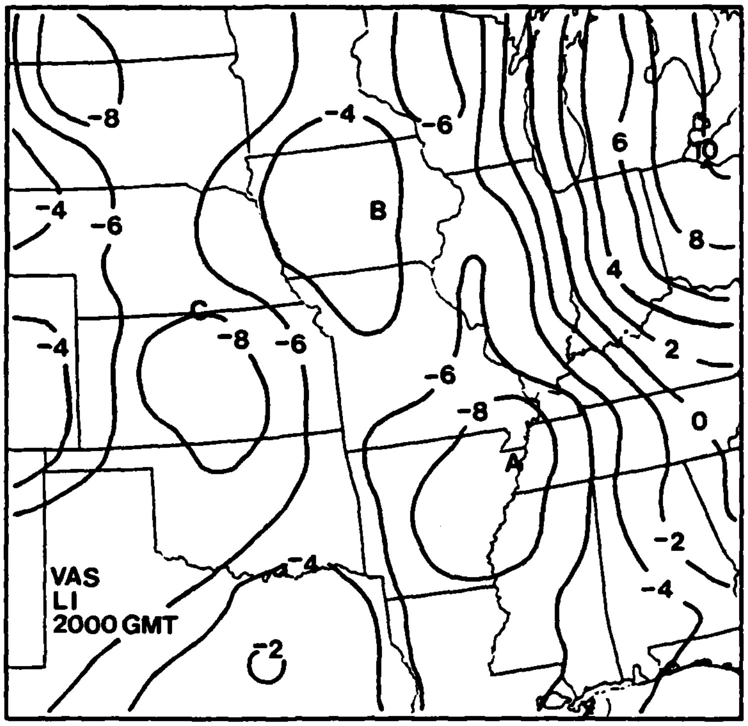



Fig. 14. Lifted Indices from rawinsonde data at 1200 GMT 21 July and 0000 GMT 22 July and from VAS data at 1700, 2000, and 2300 GMT 21 July.



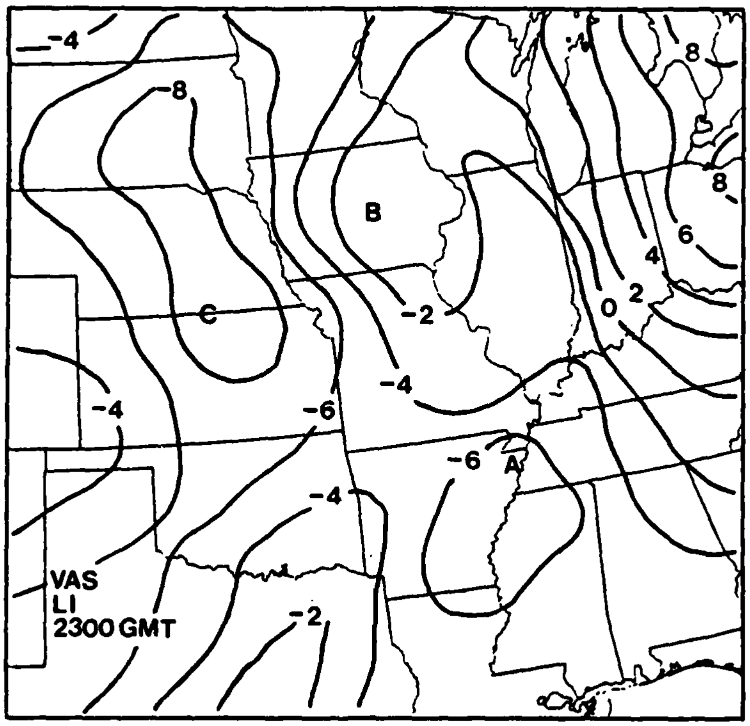




Fig. 14. Continued.

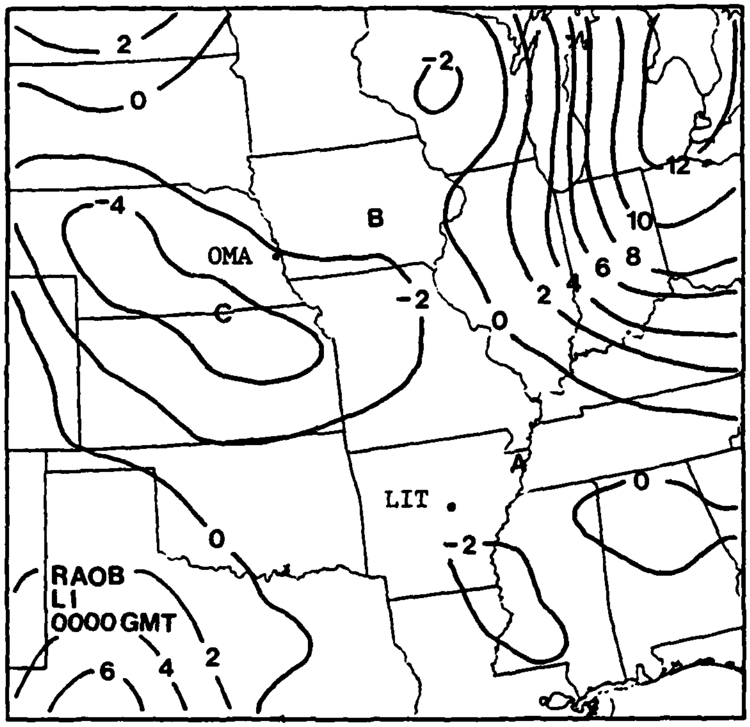



Fig. 14. Continued.

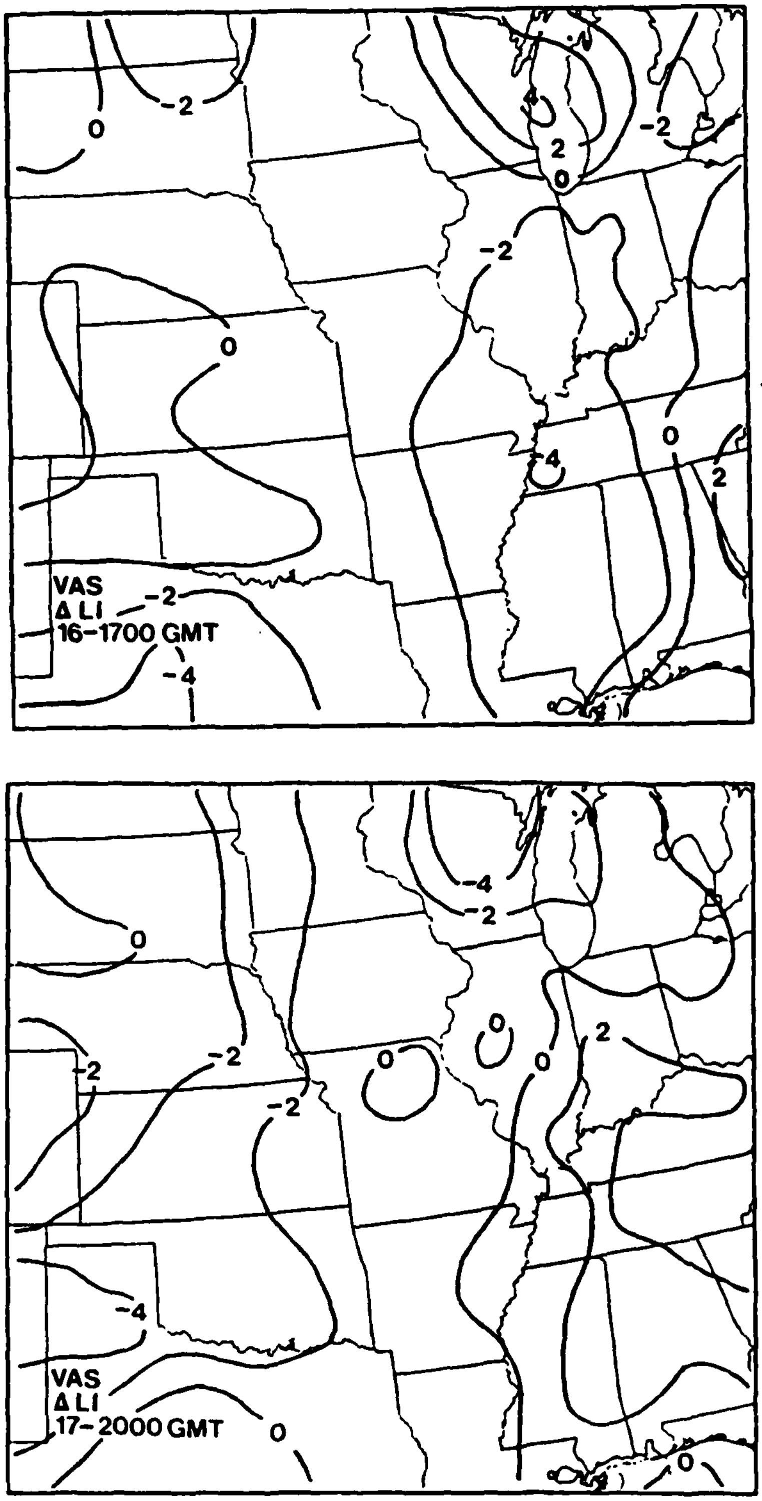
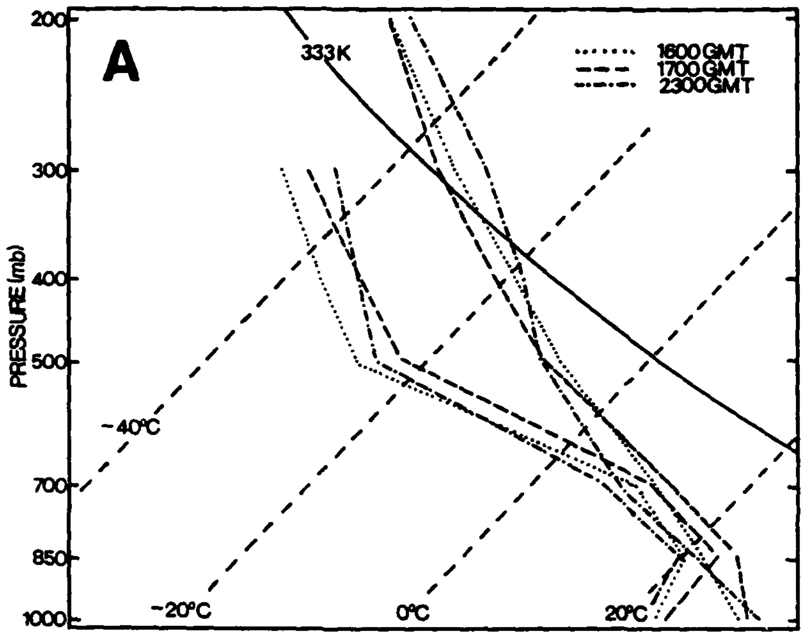



Fig. 15. Changes in the Lifted Index between 1600 to 1700 GMT and 1700 to 2000 GMT 21 July.

stability is significant since it precedes the convective outbreak. After 1700 GMT, the area experiences a return to more stable conditions.

It is informative to study the VAS and rawinsonde soundings in this major area of instability. Fig. 16 is a Skew T-log P diagram of VAS retrievals at 1600, 1700, and 2300 GMT for Point A in Figs. 11, 14. These profiles are taken from the objectively analyzed data. Thus, instead of denoting a single sounding site, they are representative of a larger region. For purposes of comparison, the rawinsonde sounding for Little Rock, Arkansas at 0000 GMT also is shown in the figure. It is obvious that the rawinsonde profile which contains numerous "significant levels" exhibits considerably more vertical detail than is given by the VAS soundings at only the mandatory levels.

Concerning the temporal changes in stability, one should first note that the 1600 GMT temperature profile (Fig. 16) is conditionally unstable below 500 mb. From 1600 to 1700 GMT, cooling aloft (even at 500 mb) and warming below produce the increasing instability seen in the spatial maps (Figs. 14-15). The resulting temperature patterns are verified by the thickness charts at 1700 GMT (Fig. 10). The trend towards instability reverses between 1700 to 2300 GMT due to warming aloft and cooling below. One should also note that the 850-700 mb layer is virtually saturated between 1600 to 2300 GMT. This enhances the real-latent instability, thereby aiding in the production of explosive



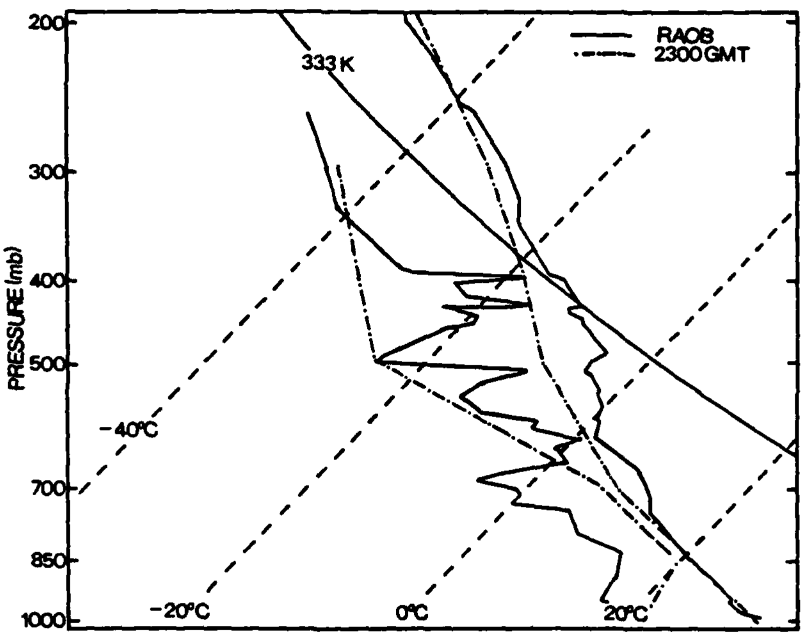




Fig. 16. Skew T-log P profiles from VAS data at 1600, 1700, and 2300 GMT 21 July and from rawinsonde data at 0000 GMT 22 July at Points A, B, and C (see Figs. 11, 14).

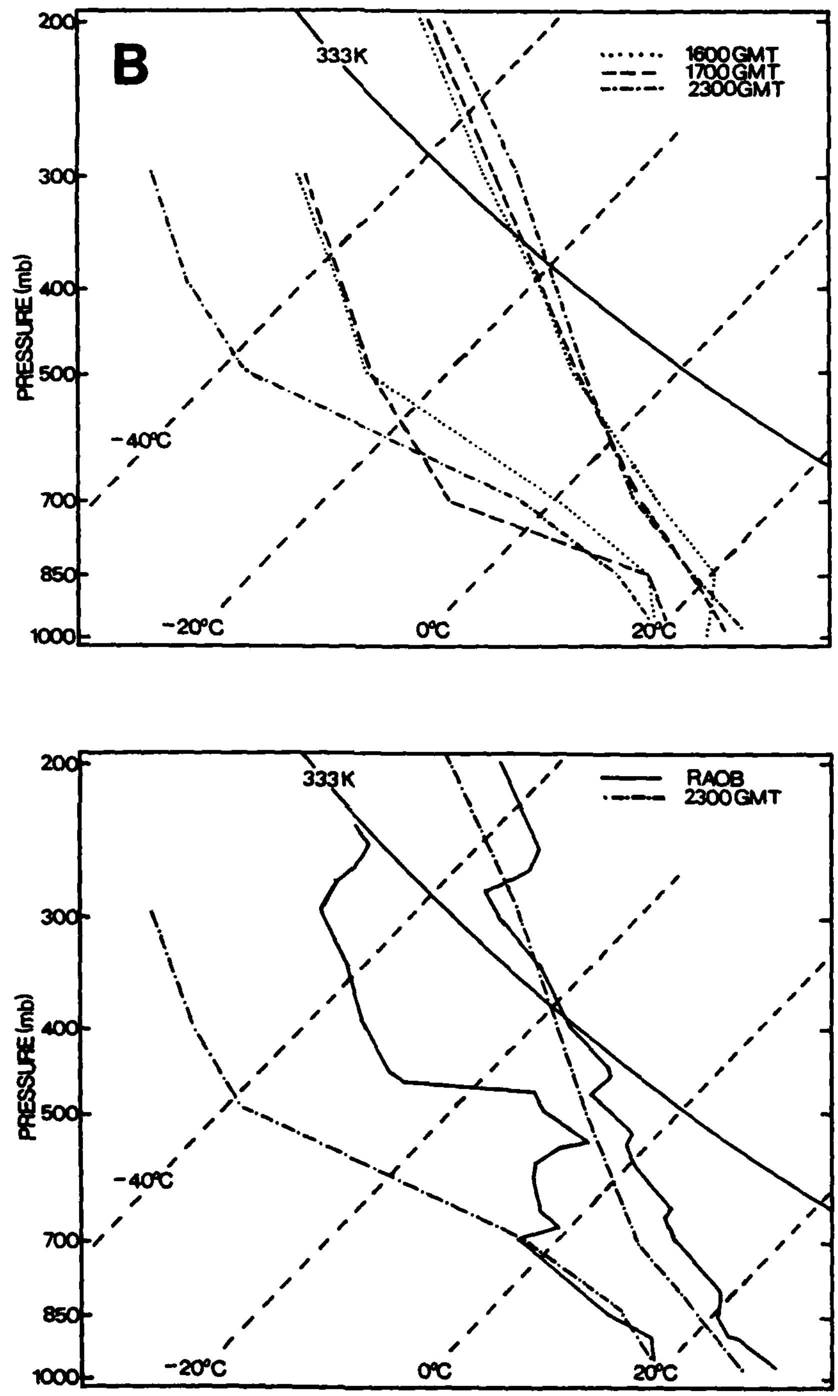



Fig. 16. Continued.

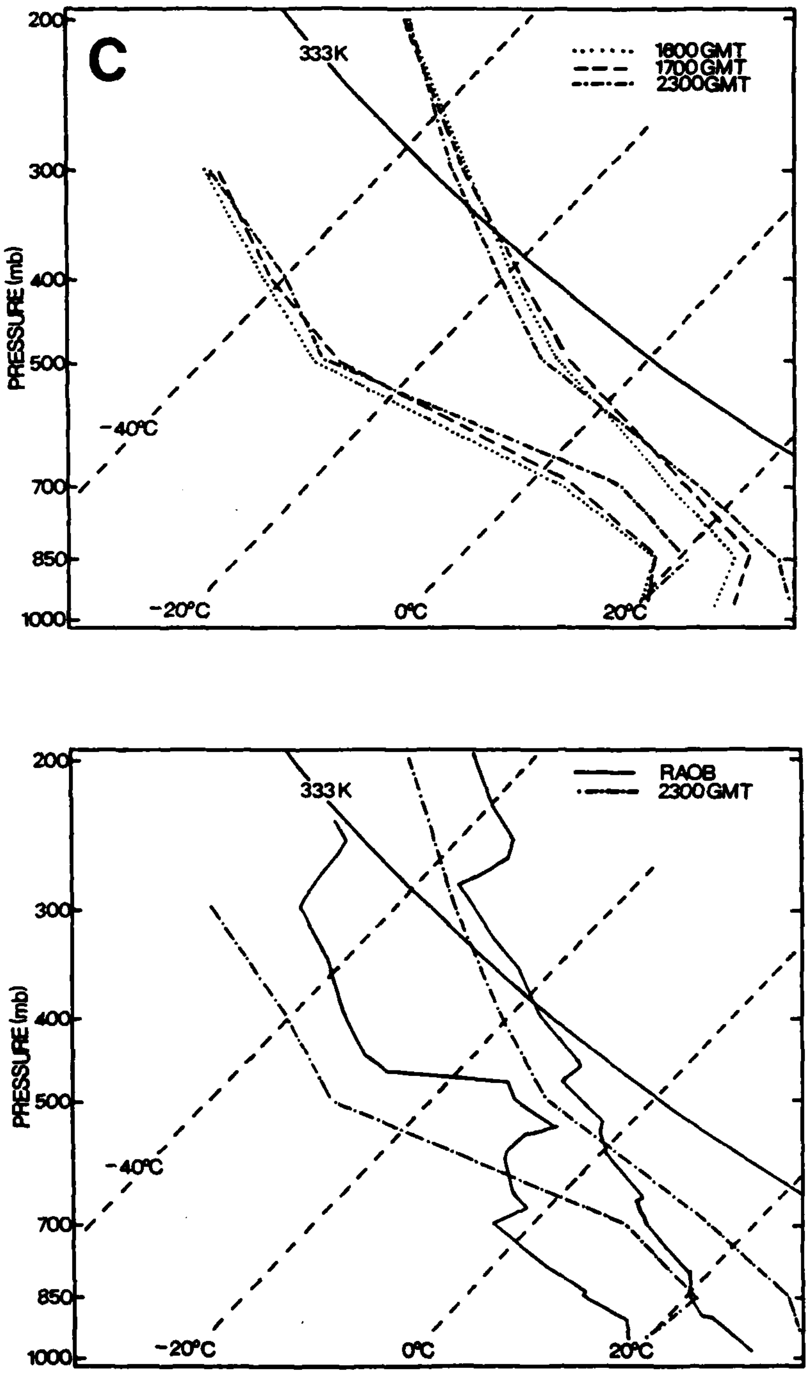



Fig. 16. Continued.

convection.

The satellite's overestimate of instability is explained by comparing the VAS profile at 2300 GMT with the Little Rock sounding at 0000 GMT (Fig. 16). VAS indicates relatively cool conditions at and above 500 mb but values are quite similar below 750 mb. The satellite-generated dewpoint profile is comparatively moist below 650 mb but is drier aloft. Thus, the VAS retrievals denote more of a convectively unstable environment.

A second interesting feature is seen in the VAS-derived stability pattern (Fig. 14). At 1700 GMT, a small area of comparative stability is evident over Iowa. Values of LI have not appreciably changed since 1600 GMT, and there is little variation between 1700 to 2000 GMT as well (Fig. 15). The more stable region moves slowly eastward and is located over eastern Iowa at 2300 GMT. The feature is relatively small and is not detected by the coarser rawinsonde network at either the 1200 or 0000 GMT sounding times.

Skew T-log P diagrams for this area (Point B in Figs. 11, 14) are shown in Fig. 16. Temperature profiles for the VAS retrievals change little during the 7 h period. The dewpoint curves indicate drying above 850 mb. However, at 850 mb, the level used in computing LI, little variation occurs. Thus, as noted earlier, values of LI remain nearly constant. Compared with the nearest rawinsonde site at Omaha, Nebraska for 0000 GMT, VAS-derived temperatures at 2300 GMT are 2 to 3 $^{o}$C cooler at and

below 500 mb. In addition, the satellite denotes much drier conditions in the middle and upper troposphere. This is the layer where VAS's 6.7 µm water vapor channel (Channel 10) has a major influence on the retrievals (Fig. 1). An examination of the 6.7 µm images (not shown) verifies a mesoscale area of dryness over eastern Iowa that does not stretch into the Omaha area. This also is evident in patterns of VAS-derived precipitable water (Fig. 11). Thus, these differences between the two sounding types appear due to their not being co-located. This feature is a further example of meso α-scale information that is available from VAS.

Finally, horizontal patterns of VAS-derived LI (Fig. 14) depict the evolution of a broad area of instability over the western third of the domain. At 1700 GMT, an area of relative instability is over Kansas; however, a north-south axis of instability stretches northward to the Dakotas and southwest to Texas. The time tendency chart (Fig. 15) shows decreasing stability over Texas between 1600 to 1700 GMT. Decreases as great as 2 units occur over the Midwest between 1700 to 2000 GMT, but little change occurs between 2000 to 2300 GMT (not shown). The NMC data at 0000 GMT (Fig. 14) confirm the area of instability that formed during the day. However, values over Nebraska are only as low as -5, which is considerably more stable than the -9 seen from the VAS retrievals 1 h earlier. In spite of the satellite's apparent exaggeration of the instability, its location is similar to that

from the NMC data.

Fig. 16 shows VAS profiles for Point C (see Figs. 11, 14) at 1600, 1700, and 2300 GMT and the rawinsonde sounding for Omaha, Nebraska at 0000 GMT. One should first note that the 850-500 mb layer (Fig. 16) is nearly superadiabatic at 1600 GMT. From 1600 to 1700 GMT, few changes occur in either the temperature or dewpoint profiles. This corresponds to the lack of stability change shown in the LI tendencies (Fig. 15). However, from 1700 to 2300 GMT temperatures drop 2 to 3 $^{o}$C in the 500-400 mb layer and warm approximately 3 $^{o}$C at 850 mb (Fig. 15). This was also observed in the 500 mb analyses (Fig. 9). The result is a change in LI from -5 to -9 at Point C (Fig. 14).

The NMC data for Omaha, Nebraska, the nearest rawinsonde site, show that the LI changes from 4 to -2 during the 12 h period (Fig. 14). The rawinsonde sounding exhibits many differences from the VAS profile at 2300 GMT (Fig. 16). The satellite retrieval is comparatively warm in the lower troposphere and cool aloft, whereas the dewpoint profiles indicate relative moistness below 600 mb and dryness above. The overall effect of these differences is less stability from the VAS data.

No convection was associated with the relatively unstable area during the 12 h study period. However, a major area of thunderstorms developed over the region during the nighttime hours.

## 5. SUMMARY AND CONCLUSIONS

A case study has been conducted for a period of intense thunderstorm activity that occurred over the middle Mississippi River Valley on 21-22 July 1982. Polar-orbiter satellite data are available only every 12 h. However, this research benefited by having soundings from the GOES-VAS system at 1100, 1300, 1600, 1700, 2000, and 2300 GMT 21 July. Thus, it was possible to examine characteristics of the storm environment prior to and during the convective outbreak which began shortly after 1700 GMT. The VAS data were objectively analyzed to achieve meso α-scale resolution of atmospheric structures. Results were compared with those from the routine rawinsonde network at 12 h intervals. The goal of the investigation was to assess the relative strengths and weaknesses of VAS retrievals in diagnosing those changes in atmospheric structure after the 1200 GMT 21 July rawinsonde releases that were conducive to storm formation.

The satellite retrievals indicated several major changes in the atmosphere just prior to thunderstorm development over the middle Mississippi River Valley. These included low-level warming, middle tropospheric cooling, and a general increase in water vapor content. These factors resulted in a significant decrease in stability over the area. The instability apparently was released by several triggering mechanisms. These included large

scale vertical motions due to the eastward migration of an upper-level trough, frontal activity, afternoon surface heating, and probable storm outflow boundaries.

Thermal and moisture patterns obtained from the VAS generally showed good continuity and vertical stacking. When compared with rawinsonde-derived values at the bracketing times, the satellite retrievals produced patterns with reasonable continuity; however, several biases were observed. Most notable was the tendency for the VAS profiles to overestimate the degree of instability. A second limitation of the VAS data was that extensive cloud cover limited the number of satellite retrievals at both the 1100 and 1300 GMT observation times. With the reduction in cloud cover that followed, data gaps were not a major problem at the final four times.

Future research on this case should focus on two topics. First, it should be determined whether any of the observed atmospheric variations were significantly influenced by limitations of the retrieval algorithms. For example, small cumulus clouds over the middle Mississippi River Valley may have affected sounding quality over that area in ways that were not evident during the editing process. Also, the effects of solar contamination and surface conditions need to be investigated in greater detail. Although surface heating was a definite factor during the period, the retrieval process may have extended the warming to greater than expected altitudes and then compensated by producing cooling

within the middle layers. A second topic for additional study will be to utilize the VAS soundings to infer the vertical motions that triggered the observed convection. This effort is currently underway.

The important finding of this study is that VAS provided information about short term atmospheric trends and their locations that would have been a useful supplement to forecasters on 21-22 July 1982. Although this research has demonstrated that VAS retrievals would have been a useful forecasting tool on that particular day, it is only a single case. Thus, many additional periods having a large variety of synoptic situations need to be explored. This larger number of cases can describe the statistical attributes of the VAS retrievals and provide comparisons with the earlier systems. Even more important, they will permit potential users to understand the strengths and weaknesses of VAS under various atmospheric conditions. Only through such studies will we be able to assess whether VAS can provide the mesoscale data that is needed to improve our forecasting of these phenomena. Finally, a major effort is needed to develop new analysis techniques that seize on VAS's strengths but are not overly dependent on its limitations.

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In the Airman's Education and Commissioning Program, Mike was sent to Saint Louis University to study meteorology, and he graduated Summa Cum Laude with a second Bachelor's degree. After subsequent assignments in Texas, California, and Turkey, he was again sent to St. Louis University to study for a master's degree in meteorology. After completing his thesis, he and wife Leah will be transferred to Barksdale AFB, Louisiana where he will be the Aerospace Sciences Officer for the 26th Weather Squadron. The couple are expecting a child in mid-October.

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